Central Queensland Coal Project

Appendix 6b – Numerical Groundwater Model and Groundwater Assessment Report

Central Queensland Coal

CQC SEIS, Version 3

October 2020

NUMERICAL GROUNDWATER MODEL AND GROUNDWATER ASSESSMENT REPORT

FOR THE CENTRAL QUEENSLAND COAL PROJECT SUPPLEMENTARY ENVIRONMENTAL IMPACT STATEMENT VERSION 3 – RESPONSES TO SUBMISSIONS

JULY 2020
VERSION 5ii – FINAL

REPORT PREPARED FOR
CENTRAL QUEENSLAND COAL PTY LTD

LEVEL 17, 240 QUEEN STREET
BRISBANE QLD 4000

Mining Lease Surface Application Areas (ML 80187 & ML 700022)
Mineral Development Licence (MDL 468) and Exploration Permit for Coal (EPC 1029)
North-West of Marlborough, Central Queensland, Australia

DOCUMENT CONTROL REGISTER

Project	Version	Date	Description
HA-P2019-WAR1	1	15 Jan 2020	Draft for Peer Review Stage 1 [*Sections 1-7 Only*]
HA-P2019-WAR1	2	16 Mar 2020	Draft for Peer Review Stage 2 [*Sections 1-8 Only*] [*Excluding Uncertainty Analysis Section 8.12 and Attachment 11*]
HA-P2019-WAR1	3	5 April 2020	Draft for Peer Review Stage 3
HA-P2019-WAR1	4	29 May 2020	Draft for Final Stage Peer Review (*Addressing Peer Review Stages 1-3 Comments*)
HA-P2019-WAR1	5	8 July 2020	Final Draft (*including Enhanced River Bed Conductance Sensitivity Scenario and Other Reporting Updates*)
HA-P2019-WAR1	5i	24 July 2020	Revised Final Draft (*reflecting AGE Consultants Peer Review Stage 4 Updates and Orange Environmental GDE Updates*)
HA-P2019-WAR1	5ii	24 July 2020	Final

Role	Personnel
Author	A. Hagenbach (The HG Institute)
Internal Review	Dr D. Merrick (HydroAlgorithmics) [*Sections 6 to 8*] (30-31 March 2020)
Peer Review Stages 1-2	AGE Consultants [*Table 7-1 Only*] (20 December 2019) AGE Consultants [*Sections 1-7 Only*] (14 February 2020) AGE Consultants [*Sections 1-8 Only, excluding UA*] (6 April 2020)
Editorial Review	M. Walker (Orange Environmental) [*Sections 1-11*] (24-29 April 2020)
Peer Review Stage 3	AGE Consultants (7 May 2020)
Peer Review Stage 4	AGE Consultants (19 June 2020, 3 July 2020 & 16 July 2020)
Final Draft Review (for SEIS)	N. McIntosh (Orange Environmental) (20 July 2020)

EXECUTIVE SUMMARY

The Central Queensland Coal Project (the Project), previously known as the Styx Coal Project, is a proposed open cut coal mine and associated infrastructure development located approximately 25 kilometres north-west of Marlborough, and approximately 130 kilometres north-west of Rockhampton in Central Queensland, Australia. The Project is located within the Livingstone (Shire Council) Local Government Area.

The Project would be located within Mining Lease Surface Application Areas 80187 and 700022, which are adjacent to existing Mineral Development Licence 468 and Exploration Permit for Coal 1029. It is intended that the Project would be authorised and regulated by a site-specific environmental authority issued with conditions under Queensland legislation (i.e. *Environmental Protection Act 1994*) and an approval decision issued with conditions under Commonwealth legislation (i.e. *Environment Protection and Biodiversity Conservation Act 1999*).

The Project is located within the Styx River catchment which has a long history of coal mining. Development of the Styx Coalfields began in 1918 at the Styx No.1 State Coal Mine at Bowman, followed shortly thereafter to the south by the Styx No.2 State Coal Mine. In 1924, the Styx No.3 State Coal Mine began production at Hartley (later named Ogmore), prior to the Styx No. 2 State Coal Mine closure in 1925. From 1930 to 1948, the Bowman Coal Mining Syndicate extracted coal at the Bowman Mine within Coal Mining Lease No.227. The Styx No.3 State Coal Mine in Ogmore was finally closed in 1964. Locally, the Project is predominantly located within the Deep Creek sub-catchment of the Styx River catchment, upstream of the historic coal mining locations at Bowman and Ogmore.

The environmental impact assessment process for the Project is well-advanced, with public notification of the Environmental Impact Statement (EIS) between 6 November 2017 to 18 December 2017 following the Final Terms of Reference issued on 4 August 2017.

The Queensland Government, Commonwealth Government and advisory bodies' submissions on the EIS, Amended EIS and Supplementary EIS have been received and the most recent correspondence from the Department of Agriculture and Fisheries, Department of Environment and Science (DES); and Department of the Environment and Energy[1] relating to groundwater matters have been considered.

It is recognised that the key submissions and review comments on the EIS relating to groundwater generally reflect the specific assessment advice for the Project received from the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) on 31 July 2018 (IESC-2018-094), including previous IESC assessment advice on 15 December 2017 (IESC-2017-091). After receipt of the IESC advice in July 2018, the baseline groundwater monitoring network was substantially expanded, and independent peer review conducted.

This **Numerical Groundwater Model and Groundwater Assessment Report (this Report)** has been prepared for the Central Queensland Coal Project Supplementary EIS Version 3 – Responses to Submissions. Improvements have been made to the previous numerical groundwater model to consider the prior peer review outcomes, incorporate available datasets and consider feedback sought during consultation with Government departments, including consideration of published guidelines (and explanatory notes) released by the IESC.

During the implementation of the most recent improvements to the numerical groundwater model, including development of a robust uncertainty analysis approach, consultation with the DES has occurred with consideration of relevant feedback, in parallel with a progressive independent peer review by AGE Consultants.

The staged independent peer review relevantly concluded that appropriate parameter identifiability and uncertainty analysis had been completed (AGE Consultants, Stage 3, 7 May 2020), however it was recognised that inevitably any assessment of whether or not a modelling study meets a set of criteria is subjective. Therefore, a number of areas for further improvement were recommended, and have been duly considered and responded to within **this Report**.

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[1] On 1 February 2020, the Commonwealth Department of the Environment and Energy (DEE) was replaced with the Department of Agriculture, Water and the Environment (DAWE), however is referred as the DEE herein.

This Report demonstrates that following the robust uncertainty analysis, extensive parameter analysis and testing, and supporting justification for model concepts and complexity, improvements have been made appropriately and the predictions presented by the CQC-LF3 Groundwater Model are fit-for-purpose and achieves the overall target model confidence level classification.

Ultimately, the final peer review concludes (AGE Consultants Stage 4, 16 July 2020):

> *The modelling work has generally been completed in line with the Guiding Principles included in the Australian Groundwater Modelling Guidelines and in the IESC Uncertainty Analysis Guidance Note and we have not identified any fundamental flaws in the work which are likely to significantly effect model predictions.*

In summary, based on the improved numerical groundwater modelling (CQC-LF3) there is expected to be:

- approximately 0.5 ML/day average groundwater take during the operational life of the CQC Project, with predicted inflow to the open cut steadily increasing as the pit is developed and depth increases to the east, up to approximately 1.2 ML/day (averaged over a quarterly interval);
- substantial reduction in potentiometric head in the Styx Coal Measures (overburden and interburden) and to a lesser extent in the Styx Coal Measures (underburden) and Back Creek Group in the near vicinity of the open cut mining operation, extending to lesser magnitudes (i.e. <2 m) beyond the open cut extent up to approximately:
  - 3.5 km in the north;
  - 5 km in the north-east (at depth); and
  - 3 km in the south-east;
- some temporal drawdown predicted in the Cenozoic sediments in the near vicinity of the open cut mining operation, where the saturated water table is present (albeit gradual and localised), and is predicted to gradually recover post-mining;
- negligible changes in natural baseflow to and/or leakage from surface water systems, as a consequence of predicted reductions in potentiometric head and temporal drawdown in the near vicinity of the open cut mining operation, with predicted volumetric differentials in baseflow to and/or enhanced leakage as follows (presented as peak estimates for the relevant averaged period):
  - up to approximately 0.008-0.009 m^3/s from Tooloombah Creek, upstream of the Deep Creek confluence (9.3 km reach);
  - up to approximately 0.005-0.006 m^3/s from Deep Creek (17.5 km reach);
  - less than 0.0002 m^3/s from Tooloombah Creek, downstream of the Deep Creek confluence (1.7 km reach); and
  - less than 0.0003 m^3/s from the Styx River (6.1 km reach);
- negligible impact on groundwater yield, levels and quality of private landholder bores in all hydrogeological units, with the exception of one private landholder bore (BH28) screened in the deeper consolidated aquifer immediately south-west of ML 80187;
- no appreciable change in groundwater quality, as a result of the CQC Project, both:
  - during the open cut mining operation as the advancing pit would remain as a temporal and localised sink to which surrounding groundwaters would flow toward; and
  - in the long-term as the voids would be backfilled (in accordance with a Mineral Waste Management Plan) and groundwater levels substantially recover over many decades by enhanced rainfall recharge/ infiltration at the surface across the backfill spoil and emplacement areas.

Whilst available datasets and records suggest substantial recovery of groundwater pressures and levels at the historic mine workings at Ogmore and Bowman has already occurred, it is expected they will continue to gradually recover over the coming decades as well.

Cumulatively, the predicted groundwater drawdown effects as a result of the CQC Project do not extend as far as the historic Ogmore mine workings (some 8 km to the north and downstream beneath the Styx River) to result in any superposition effects and therefore is not expected to result in any discernible change to the location of the freshwater-saltwater interface. That is, even if the interface was to be transient (or static) north of the historic Ogmore workings, there would not be expected to be any discernible change due to the CQC Project alone. The cumulative effects of the historic mine workings at Bowman (beyond those predicted for the CQC Project alone) are predicted to be negligible given the limited extent and proximity of the historic workings in the north, and continued recovery since the cessation of mining.

The potential impacts of the CQC Project on surface water resources are assessed and presented separately by Orange Environmental Pty Ltd (2020) and WRM Water & Environment (2020). Similarly, the potential impacts on groundwater dependent ecosystems (including combined hydrogeological and hydrological changes i.e. catchment excision and controlled releases) are assessed and presented separately by Orange Environmental Pty Ltd (2020) and Eco Logical Australia Pty Ltd (2020a).

The following key groundwater-related monitoring recommendations are made going forward:

- CQCPL should consider installing an additional groundwater monitoring bore (deep standpipe) to the north / north-east of Open Cut 2, but to the west of the mapped fault (e.g. between WMP05 and WMP10) and south of the historic mine workings at Ogmore within the first three (3) years of the operation for the purposes of model prediction validation and adaptive management[2];
- CQCPL should continue baseline groundwater level measurements and groundwater quality sampling as outlined in the proposed groundwater monitoring program in **this Report**, with the objective to augment current statistical datasets to inform the final (or future) EA condition investigation trigger levels; and
- CQCPL should continue baseline surface water flow gauging and surface water quality sampling as outlined in the proposed groundwater monitoring program in **this Report**, with the objective to augment current datasets to inform the final (or future) EA conditions, and provide the opportunity for future groundwater model validation.

It is understood future monitoring programs would be outlined and integrated where relevant with the suite of other management plans developed for the CQC Project including:

- Water Management Plan;
- Erosion and Sediment Control Plan(s);
- Mineral Waste Management Plan;
- Groundwater Dependent Ecosystem Management and Monitoring Plan; and
- Receiving Environment Monitoring Program.

The integration of the above would be finalised in the groundwater monitoring program prepared in accordance with the proposed EA condition, developed by a suitably qualified person and submitted to the administering authority for review and comment, including timeframes for staged installation and commissioning for the proposed supplementary groundwater monitoring locations, as required.

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[2] In April 2020, CQCPL installed WMP21B to a total depth of approximately 95 m with screen targeting the overburden of the Styx Coal Measures in line with the key groundwater-related monitoring and management recommendation.

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1.0 INTRODUCTION

1.1 CENTRAL QUEENSLAND COAL (CQC) PROJECT

The Central Queensland Coal Project (CQC Project), previously known as the Styx Coal Project, is a proposed open cut coal mine and associated infrastructure development located approximately 25 kilometres (km) north-west of Marlborough, and approximately 130 km north-west of Rockhampton in Central Queensland (Qld), Australia. The CQC Project is located within the Livingstone (Shire Council) Local Government Area (LGA).

Central Queensland Coal Pty Ltd (CQCPL) is the proponent for the CQC Project.

The CQC Project would be located within Mining Lease Surface Application Areas (ML) 80187 and ML 700022, which are within existing Mineral Development Licence (MDL) 468 and adjacent Exploration Permit for Coal (EPC) 1029. It is intended that the CQC Project would be authorised and regulated by a site-specific environmental authority (EA).

1.1.1 Environmental Impact Assessment Process – Approvals Status

The environmental impact assessment process for the CQC Project is well-advanced, with a chronological summary to date as follows:

- **24 January 2017:** An Application to Voluntarily Prepare an Environmental Impact Statement (EIS) for the CQC Project was approved[3] by the then Qld Department of Environment and Heritage Protection (DEHP) (now the Department of Environment and Science [DES]).
- **3 February 2017:** A decision was made[4] by the Commonwealth Department of the Environment and Energy (DEE)[5] that the CQC Project was a Controlled Action (EPBC 2016/7851) and the bilateral agreement between the Commonwealth and Qld Governments[6] would apply for the EIS process.
- **10 April 2017 to 8 June 2017:** Public notification of the Draft Terms of Reference (TOR) for the CQC Project EIS was made, inviting written comments.
- **4 August 2017:** The Final TOR for the CQC Project EIS was approved by the DEHP.
- **6 November 2017 to 18 December 2017:** Public notification of the CQC Project EIS was made, and copies of the submitted EIS made available, inviting written submissions.
- **22 May 2018:** A response to written submissions and Amended EIS was lodged with the DES.
- **20 December 2018:** A response to the DES and other advisory bodies' submissions on the Amended EIS was lodged with a Final Amended EIS lodged (Supplementary EIS).
- **14 June 2019:** Government agency comments in relation to Supplementary EIS were received with advice from the DES to provide information to adequately respond to key submissions and review comments on the EIS. The DES comments were later revised and provided in August 2019.

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[3] Under Section 72 of the *Environmental Protection Act, 1994* (refer **Section 2.1.1**).

[4] Under Section 75 of the *Environment Protection and Biodiversity Conservation Act, 1999* (refer **Section 2.2.1**).

[5] On 1 February 2020, the DEE was replaced with the Department of Agriculture, Water and the Environment (DAWE), however is referred as the DEE herein.

[6] Under Section 45 of the *Environment Protection and Biodiversity Conservation Act, 1999* (refer **Section 2.2.1**).

1.2 ASSESSMENT SCOPE AND OBJECTIVES

HydroAlgorithmics Pty Ltd was commissioned to develop the **Numerical Groundwater Model and Groundwater Assessment Report (this Report)** to be used in support of a response to the relevant *Agency comments in relation to amended EIS 2019* (received 14 June 2019). A summary of the key submissions and review comments on the EIS relating to groundwater are provided in **Attachment 1** including submissions from the following:

- Qld Department of Agriculture and Fisheries (DAF) (**Table A1-1**);
- DES (**Table A1-2**); and
- DEE (**Table A1-3**).

It is recognised that the above key submissions and review comments on the EIS relating to groundwater generally reflect the prior assessment advice for the CQC Project received from the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) on 31 July 2018 (IESC-2018-094) including previous IESC assessment advice on 15 December 2017 (IESC 2017-091).

It is also noted that on 6 January 2019, HydroAlgorithmics Pty Ltd had completed a previous peer review of the groundwater modelling, and groundwater assessment in general, based on review of the following reports prepared by CDM Smith (2018a; 2018b):

- *Central Queensland Coal Project Supplementary Environmental Impact Statement: Appendix 6 – Groundwater Technical Report*. 17 May 2018, 86p.
- *Central Queensland Coal Project Supplementary Environmental Impact Statement: Chapter 10 – Groundwater.* 18 May 2018, 233p.

In parallel with HydroAlgorithmics Pty Ltd peer review, an independent third-party review of *Appendix A6 - Groundwater Technical Report, Draft* dated 30 November 2018 (CDM Smith, 2018d) was undertaken by GHD Pty Ltd.

Separately, an incomplete peer review of the CDM Smith groundwater model was conducted by Australasian Groundwater and Environmental (AGE) Consultants and reported in a letter dated 5 February 2019. The peer review was completed in a staged manner during the preparation of **this Report**, with the Stages 1-3 Peer Review findings progressively received on 20 December 2019, 14 February 2020, 6 April 2020 (interim) and 7 May 2020.

A reconciliation against the prior IESC assessment advice for the CQC Project (dated 31 July 2018), including subsequent fatal flaw checklists published in the IESC's *Information Guidelines Explanatory Note: Uncertainty Analysis – Guidance for Groundwater Modelling within a Risk Management Framework* (dated 17 December 2018), as well as comments in the independent third-party review by GHD Pty Ltd (dated 20 December 2018), matters raised in the HydroAlgorithmics Pty Ltd peer review (dated 6 January 2019) and AGE Consultants' previously incomplete peer review of the groundwater model (dated 5 February 2019) and Stage 1-3 Peer Review findings relating to groundwater are also provided in **Attachment 1 (Tables A1-4 and A1-5)** and **Attachment 2 (Tables A2-1 to A2-6)** respectively. For completeness, AGE Consultant's final Stage 4 peer review letter is provided in **Attachment 2**.

In addition, **this Report** has been prepared cognisant of contemporary requirements of Commonwealth and State regulatory and advisory agencies.

The numerical groundwater modelling has been undertaken with the objective to be consistent with the Australian Groundwater Modelling Guidelines issued by the National Water Commission in June 2012[7] and prepared to address the relevant groundwater-related:

- requirements of the Final TOR for the CQC Project, dated 4 August 2017; and
- information requirements contained in the IESC's *Information Guidelines for proponents preparing coal seam gas and large coal mining development proposals* (dated May 2018) (Information Guidelines), considering the subsequently finalised explanatory notes and fact sheet:
    - *Information Guidelines Explanatory Note: Uncertainty Analysis – Guidance for Groundwater Modelling within a Risk Management Framework* (dated 17 December 2018);
    - *Information Guidelines Explanatory Note: Assessing Groundwater-Dependent Ecosystems* (dated 8 March 2019);
    - *Information Guidelines Explanatory Note: Deriving Site-Specific Guideline Values for Physico-chemical Parameters and Toxicants* (dated 7 June 2019)[8]; and
    - *Environmental Water Tracers in Environmental Impact Assessments for Coal Seam Gas and Large Coal Mining Developments – Factsheet* (Office of Water Science [OWS], 2020).

A detailed reconciliation against the groundwater-related requirements of the Final TOR for the CQC Project is provided in **Table 1-1**. For completeness, a detailed reconciliation against the groundwater-related requirements of the IESC Information Guidelines (dated May 2018) is presented in **Section 11.2**.

Table 1-1
Final Terms of Reference for the CQC Project - Reconciliation Table for Groundwater-Related Matters

Section in Final TOR	Specific Requirement	How Considered/ Addressed
Section 1.1 [Introduction]	The key information requirements of the EP Act that must be addressed in the EIS are: … • the requirements of section 40 of the EP Act, which specifies the purpose of an EIS and of the EIS process; • sections 125, 126 and 126A which set out the general information requirements for applications for an environmental authority (EA); …	Section 2.1.1 and 2.1.2
Section 1.2.2 [Project Description]	Key components of the Project include: … • two open cut pits with a maximum production rate of 10 Mtpa (combined HGTC and SSCC); … • waste rock dumps, mine water dams and associated infrastructure; • raw and potable water supply from local aquifers and surface water; …	Section 8.3
Section 1.2.4 [EPBC Act 1999]	The controlling provisions are: … • sections 24D and 24E (a water resource, in relation to coal seam gas development and large coal mining development). The project will be assessed under the bilateral agreement between the Commonwealth and the State of Queensland (section 45 of the EPBC Act) using the EIS prepared under the EP Act.	Sections 2.2.1 and 11.0

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[7] Barnett B, Townley LR, Post V, Evans RE, Hunt RJ, Peeters L, Richardson S, Werner AD, Knapton A and Boronkay A, 2012, *Australian groundwater modelling guidelines*, Waterlines Report Series No. 82, National Water Commission, Canberra. ISBN: 978-1-921853-91-3.

[8] It is noted that groundwater and groundwater dependent ecosystems are not covered in the explanatory note, and whilst the concepts presented may be relevant to groundwater, it is explicitly recommended in the explanatory note that specific advice be sought regarding deriving suitable groundwater guideline values.

Table 1-1 (Continued)
Final Terms of Reference for the CQC Project - Reconciliation Table for Groundwater-Related Matters

Section in Final TOR	Specific Requirement	How Considered/ Addressed
Section 7.2 [Site Description]	Describe and map in plan and cross-sections the geology and terrestrial and/or coastal landforms of the project area. Indicate the boundaries of water catchments that are significant for the drainage of the site. Show geological structures, such as aquifers, faults and economic resources that could have an influence on, or be influenced by, the project's activities.	Sections 3.0, 4.0, 5.0 and 6.0
Section 8 [Assessment of Environmental Matters - Environmental Values]	Identify and describe the environmental values that must be protected for all the relevant matters. … Consider all available baseline information relevant to the environmental risks of the project, including seasonal variations. Describe the quality of all information, in particular the source of the information, how recent the information is, how the reliability of the information was tested, and any uncertainties in the information.	Sections 3.0, 4.0, 5.0, 6.2, 8.11 and 8.12
Section 8 [Assessment of Environmental Matters - Impact Assessment]	Assess the impacts of the project on environmental values. Impact assessment must address: • both short-term and long-term scenarios, and state whether any relevant impacts are likely to be irreversible; • consider when determining the scale of an impact, the impact's intensity, duration, cumulative effect, irreversibility, the risk of environmental harm, management strategies and offsets provisions; • the potential for unforeseen impacts and the risks associated with unlikely but potentially major impacts; • short, medium and long-term, permanent, temporary, positive and negative effects as well as impact interactions.	Sections 9.0 and 11.0
Section 8 [Assessment of Environmental Matters – Cumulative Assessment]	Assess the cumulative impacts of the project and other activities on environmental values. Impact assessment must address: • the environmental values of land, air and water, public health and the health of terrestrial and aquatic ecosystems; • the scale, intensity, duration or frequency of the impacts; • impacts created by the activities of other adjacent, upstream and downstream developments and landholders.	Sections 3.4, 5.2, 5.3, 8.10 and 9.0
Section 8 [Assessment of Environmental Matters - Management]	Propose and describe avoidance, mitigation and management strategies for the protection or enhancement of identified environmental values. Proposed strategies must: • adhere to EHP's management hierarchy: (a) to avoid; (b) to minimise or mitigate; (c) to offset, if necessary and possible; • include an adaptive management approach to provide confidence that, based on current technologies, the impacts can be effectively managed over the long-term; • be described in context of EHP's model conditions and/or site-specific, outcome-focussed conditions that can be measured and audited; • identify and describe any global leading practice environmental management that would apply for unproven elements of a resource extraction or processing process, technology or activity.	Sections 9.0, 10.0 and 11.0
Section 8, Table 1 [Matter - Water]	The activity will be operated in a way that protects environmental values of waters. The activity will be operated in a way that protects the environmental values of groundwater and any associated surface ecological systems. The activity will be managed in a way that prevents or minimises adverse effects on wetlands.	Sections 6.2, 9.3 and 10.0

Table 1-1 (Continued)
Final Terms of Reference for the CQC Project - Reconciliation Table for Groundwater-Related Matters

Section in Final TOR	Specific Requirement	How Considered/ Addressed
Section 8, Table 1 [Matter - Water Resources]	With regard to water resources, the project must meet the following objectives: • equitable, sustainable and efficient use of water resources; • maintenance of environmental flows and water quality to support the long-term condition and viability of terrestrial, riverine, wetland, lacustrine, estuarine, coastal and marine ecosystems, in a way that maintains the ecological processes on which aquatic biota depend; • Identification of environmental values and establishment of pre-disturbance (baseline) water quality objectives (WQOs) for surface- and ground- waters suitable for use as assessment criteria in accordance with appropriate national and state guidelines and policies; • maintenance of the stability of beds and banks of watercourses, and the shores of waterbodies, estuaries and the coast; • maintenance of supply to existing users of surface and groundwater resources, including during construction, operation and decommissioning of the project.	Sections 3.0, 4.0, 5.0, 6.0, 9.0 and 10.0
Section 8 [Assessment of Environmental Matters - Critical Matters]	A critical matter is defined as an aspect of the proposal that has one or more of the following characteristics: … • It is relevant to a controlling provision under the EPBC Act. • It raises obligations under any other legislation applicable for the proposed project (e.g. Water Act 2000). Critical environmental matters identified for this project which the EIS must give priority are: … • water quality and quantity	Sections 2.1.2, 2.2.1, 3.2.7, 5.5, 9.1, 6.2, 9.2 and 11.0
Section 8.2.1 [Rehabilitation (v)]	Notwithstanding that management techniques may improve over the life of the project, and legislative requirements may change, the EIS needs to give confidence that all potential high-impact elements of the project (e.g. spoil dumps, voids, tailings and water management dams, creek diversions or crossings, borrow pits) are capable of being managed and rehabilitated to achieve acceptable land suitability, to be safe, stable, non-polluting and self-sustaining, and to prevent upstream and downstream surface and groundwater contamination.	Sections 7.9, 8.3 and 8.11 [*Rehabilitation Design and Surface Water Reported Separately in Xenith Consulting (2020) and WRM Water & Environment (2020)*]
Section 8.3 [Water Quality]	The assessment of water quality is considered a critical matter given the proximity of the Great Barrier Reef World Heritage Area, the presence of a wetland of national significance within the project area, and usage of water resources for grazing purposes in the area.	Sections 2.2, 3.2.7, 3.4, 3.5, 5.5, 6.2, 9.2 and 11.1
	Conduct impact assessment in accordance with the EHP's EIS information guideline—Water.	Section 9.0
	Define and/or establish the relevant water quality objectives applicable to the environmental values, and demonstrate how these will be met by the project during construction, operation and decommissioning. Quantify sediment and contaminant load increases in streams and to the reef as a result of mining operations.	Sections 6.2 and 10.9 and Attachment 6 [*Surface Water Reported Separately in WRM Water & Environment (2020)*]
	Detail the chemical, physical and biological characteristics of surface waters and groundwater within the area that may be affected by the project and at suitable reference locations using sufficient data to define background conditions and natural variation in accordance with appropriate national and state guidelines and policies.	Sections 3.0, 4.0 and 5.0

Table 1-1 (Continued)
Final Terms of Reference for the CQC Project - Reconciliation Table for Groundwater-Related Matters

Section in Final TOR	Specific Requirement	How Considered/ Addressed
Section 8.3 [Water Quality] [*Cont.*]	Describe the quantity, quality, location, duration and timing of all potential and/or proposed releases of contaminants addressing applicable standards from any relevant regional water quality management plans, strategies, or guidelines relating to water quality. Releases may include controlled water discharges to surface water streams, uncontrolled discharges when the design capacity of storages is exceeded, spills of products during loading or transportation, spills of product from the conveyor, contaminated run-off from operational areas of the site (including seepage from waste rock dumps), or run-off from disturbed acid sulphate soils.	Sections 8.3.5, 9.0 and 10.0 [*Surface Water Reported Separately in WRM Water & Environment (2020)*]
	Assess the likely impacts of any releases from point or diffuse sources on all relevant environmental values of the receiving environment, including environmentally sensitive areas; such as the Great Barrier Reef World Heritage Area and Broad Sound Directory of Important Wetlands in Australia (DIWA) nationally important wetland as well as near-field and mid-field locations. The assessment should consider the quality and hydrology of receiving waters and the assimilative capacity of the receiving environment.	Sections 2.2, 3.5.1, 6.2, 8.3.5 and 9.0 [*Surface Water Reported Separately in WRM Water & Environment (2020)*]
	Describe how impacts on water quality objectives and environmental values would be avoided or minimised through the implementation of management strategies that comply with the management hierarchy and management intent of the Environmental Protection (Water) Policy 2009[9]. Appropriate management strategies may include the use of erosion and sediment control practices, and the separation of clean storm water run-off from the run-off from disturbed and operational areas of the site.	Section 10.0 [*Surface Water Reported Separately in WRM Water & Environment (2020) and erosion and sediment control practices in Engeny Water Management (2020)*]
	Describe how monitoring would be used to demonstrate that objectives were being assessed, audited and met. For example, provide measureable criteria, standards and/or indicators that will be used to assess the condition of the ecological values and health of surface water environments. Propose corrective actions to be used if objectives are not being met.	Section 10.0
Section 8.4 [Water Resources]	The assessment of surface water and groundwater resources is considered a critical matter given the usage of water resources for grazing purposes in the area.	Sections 3.4, 5.2.2, 8.7.1 and 9.0
	Conduct impact assessment in accordance with the EHP's EIS information guidelines—Water.	Section 9.0
	Describe present and potential users and uses of water in areas potentially affected by the project, including municipal, agricultural, industrial, recreational and environmental uses of water.	Sections 5.2, 5.3 and 6.2
	Provide details of any proposed changes to, or use of, surface water or groundwater. Identify any approval or allocation that would be needed under the Water Act 2000.	Sections 2.1.2 and 10.3
	Describe all aquifers that would be impacted by the project, including the following information: • nature of the aquifer/s • geology/stratigraphy - such as alluvium, volcanic, metamorphic • aquifer type - such as confined, unconfined • depth to and thickness of the aquifers • groundwater quality and volume • current use of groundwater in the area • survey of existing groundwater supply facilities (e.g. bores, wells, or excavations)	Sections 4.0, 5.0, 6.0, 7.0, 8.0, 9.0 and 10.0

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[9] As described in **Section 2.1.3**, the Environmental Protection (Water) Policy 2009 was replaced by the Environmental Protection (Water and Wetland) Policy 2019.

Table 1-1 (Continued)
Final Terms of Reference for the CQC Project - Reconciliation Table for Groundwater-Related Matters

Section in Final TOR	Specific Requirement	How Considered/ Addressed
Section 8.4 [Water Resources] [*Cont.*]	• information to be gathered for analysis to include: ○ location ○ pumping parameters ○ drawdown and recharge at normal pumping rates, and ○ seasonal variations (if records exist) of groundwater levels • proposal to develop network of groundwater monitoring bores before and after the commencement of the project.	As above
	Include maps of suitable scale showing the location of diversions and other water-related infrastructure in relation to mining infrastructure. Detail any significant diversion or interception of overland flow. Assess the potential impacts of any new water infrastructure (including diversions, pits, dams, etc.) and any proposed changes to water supply or take, on ground and surface water hydrology, quality and hydrological processes.	Section 8.3 (Figure 8-1) *[Surface Water Reported Separately in WRM Water & Environment (2020)]*
	Describe the options for supplying water to the project and assess any potential consequential impacts in relation to the objectives of any water resource plan and resource operations plan that may apply.	Sections 2.1.2 and 8.3
	Describe how 'make good' provisions would apply to any water users that may be adversely affected by the project.	Section 10.8
	Describe the proposed supply of potable water for the project, including temporary demands during the construction period. Also describe on-site storage and treatment requirements for waste water from accommodation and/or offices and workshops.	*[Not a Groundwater-Related Matter; Reported Separately in the SEIS]*
	Describe the practices and procedures that would be used to avoid or minimise impacts on water resources.	Section 10.0
	Quantify the volume of all takes from the groundwater system (including pit dewatering, degassing, etc.) and assess the impacts on groundwater levels, quality and ecosystem interactions for each aquifer and any implications for surface-groundwater interactions.	Sections 8.4, 8.5, 8.6 and 8.7
Section 8.4.1 [The Independent Expert Scientific Committee]	The EIS must include a specific section responding to the information requirements contained in the Independent Expect Scientific Committee's (IESC's) Information guidelines for proposals relating to the development of coal seam gas and large coal mines where there is a significant impact on water resources (Commonwealth of Australia, 2015).	Section 11.2, Table 11-1 and Attachment 1 (Tables A1-4 & A1-5)
Section 8.5 [Flooding]	The assessment of surface water and groundwater resources is considered a critical matter given the use of the area for cattle grazing and the need to protect the environmental values of water resources. …	Section 3.3 *[Surface Water Reported Separately in WRM Water & Environment (2020)]*
Section 8.7 [Flora and Fauna]	The assessment should include the following key elements: … • terrestrial and aquatic ecosystems (including groundwater-dependent ecosystems) and their interactions …	Sections 5.3.2, 8.7.2 and 10.5 [*Assessment of Consequential Impacts on Terrestrial and Aquatic Ecosystems Reported Separately in Eco Logical Australia (2020a; 2020b)*]
Appendix 3 [Description of the Environment including MNES]	It is recommended that this include the following information: … • A description of the surface and groundwater resources which may be impacted by the action, …	Sections 5.0, 8.0, 9.0 and 11.0

Table 1-1 (Continued)
Final Terms of Reference for the CQC Project - Reconciliation Table for Groundwater-Related Matters

Section in Final TOR	Specific Requirement	How Considered/ Addressed
Appendix 3 [Avoidance and Mitigation Measures]	A consolidated list of measures proposed to be undertaken to avoid, mitigate and manage the relevant impacts of the action on MNES, including: … • including how impacts to surface water flow and quality and to groundwater quality and groundwater regimes will be managed during construction, operation and decommissioning of the project • how final voids will be managed to avoid ongoing impacts to MNES following the end of the operational phase of the project …	Sections 8.3.6 and 10.0

1.2.1 Previous Studies, Plans, Programs and Reports

A comprehensive list of references is provided in **Section 13.0**, however the following list of documentation is highlighted as having provided important background information, data and context that have been used in developing **this Report**:

- *Styx Coal Project Initial Advice Statement* (CDM Smith, December 2016);
- *Central Queensland Coal Project Environmental Impact Statement* (CDM Smith, October 2017);
- *Central Queensland Coal Project Supplementary Environmental Impact Statement* (SEIS) (CDM Smith, December 2018), including:
    - SEIS Chapter 3 – Project Description;
    - SEIS Chapter 8 – Waste Rock (including geochemical testwork by RGS Environmental in 2012);
    - SEIS Chapter 9 – Surface Water (including water quality, flooding and stormwater drainage assessments, regulated structures assessments, and mine-affected water release strategy);
    - SEIS Chapter 10 – Groundwater (CDM Smith, December 2018f);
    - SEIS Chapter 11 – Rehabilitation and Decommissioning;
    - SEIS Chapter 14 – Terrestrial Ecology;
    - SEIS Chapter 15 – Aquatic Ecology;
    - SEIS Chapter 16 – Matters of National Environmental Significance;
    - SEIS Chapter 22 – Key Commitments;
    - SEIS Chapter 23 – Draft EA Conditions;
    - SEIS Appendix A3 – Soil Survey Results (ALS, 2017);
    - SEIS Appendix A4b – Geotechnical Assessment (Cardno, May 2018);
    - SEIS Appendix A5a – Surface Water and Groundwater Quality Results (including Landholder Bore Survey) (2017-2018);
    - SEIS Appendix A5b – Preliminary Surface Water Resources Technical Report (Yeats Consulting Engineers, April 2012);
    - SEIS Appendix A6 – Groundwater Technical Report (CDM Smith, December 2018);
    - SEIS Appendix A9e – Aquatic Ecology Results (ALS Water Science Group, August 2011);

  - SEIS Appendix A9f – Stygofauna Results (Yeats Consulting, July 2012); and
  - SEIS Appendix A23 – IESC Guideline Checklist.

CDM Smith (2017b; 2018f and 2018g) present conceptual models upon which the numerical groundwater flow modelling used for **this Report** are based, with relevant updates and refinements.

This Report has been completed with reliance on earlier work done by others, as noted above. In particular, characterisation of existing groundwater resources was largely completed by CDM Smith (2017b; 2018f and 2018g) as a separate study, however, has since been supplemented with additional hydrogeological information and datasets summarised herein.

1.3 STRUCTURE OF THIS REPORT

The framework for **this Report** has been developed cognisant of relevant guidelines, as well as targeting responses to the government submissions, with the report structure as follows:

Section 1.0:	**Introduction** – Provides background to the proposed CQC Project, including the environmental impact assessment process to date, and defines the assessment scope and objectives.
Section 2.0:	**Regulatory Framework** – Provides an overview of the State and Commonwealth regulatory framework relating to groundwater and applicable to the CQC Project.
Section 3.0:	**Hydrological and Landscape Setting** – Describes the climate, topography, drainage features, tidal influence and flooding, anthropogenic land use and mapped wetlands at the CQC Project and surrounds.
Section 4.0:	**Geology, Soils, Geochemistry and Geomorphology** – Describes the geology, soil landscapes and geochemical abundance (including geochemical characterisation), and combined with the hydrological and landscape setting information, culminates in a geomorphological description of the CQC Project area and surrounds.
Section 5.0:	**Groundwater Datasets and Dependent Assets** – Presents the comprehensive baseline groundwater datasets compiled for the CQC Project during several detailed groundwater monitoring and investigation campaigns between 2012 and 2019, including additional works completed *viz*.: targeted hydrogeological testwork by AMEC (2019); transient electromagnetic (TEM) survey by Groundwater Imaging (2019); and fluvial geomorphology assessment by Fluvial Systems Pty Ltd (2020); to support the refinements to the groundwater conceptualisation and numerical groundwater model.
Section 6.0:	**Conceptual Groundwater Model, Environmental Values and Water Quality Objectives** – Describes the conceptual groundwater model for the CQC Project area and surrounds, with comparisons to previous conceptual models developed by CDM Smith (2017b; 2018f and 2018g), and justified refinements including consideration of key submissions and review comments on the EIS, IESC assessment advice, matters raised in the GHD Pty Ltd independent third-party review comments, and HydroAlgorithmics Pty Ltd and AGE Consultants peer review. Based on the groundwater conceptualisation, the environmental values and water quality objectives (where applicable) are identified.
Section 7.0:	**Numerical Groundwater Model – Design, Construct and Calibration** – Describes the approach to numerical groundwater flow modelling and uncertainty analysis methodologies being applied, as well as justification for the numerical model geometry, parameterisation and discretisation. The model calibration approach is described and the results presented to support the model confidence classification.

Section 8.0: **Numerical Groundwater Model** – Forward Predictions, Identifiability Analysis and Uncertainty Analysis – Describes the model variants for forward predictions and robust uncertainty analysis (and sensitivity scenarios) based on properties found to be most important during the identifiability analysis.

Section 9.0: **Potential Impacts on Groundwater Resources, Dependent Assets and Environmental Values** – Describes the potential impacts on groundwater resources to address the key submissions and review comments on the SEIS.

Section 10.0: **Monitoring, Management, Licensing, Review and Mitigation Measures** – Provides recommendations for ongoing improvements to monitoring programs, management plans, future licensing requirements, review (and reporting) and mitigation / make good measures.

Section 11.0: **EPBC Significant Impact on Water Resources Guidelines** – Presents an overview of significant residual impacts and reconciliation against the IESC Information Guideline checklist for groundwater-related matters.

Section 12.0: **Conclusions** – Provides concluding remarks including summary outcomes.

Section 13.0: **References** – Lists the source documents that are referenced.

Section 14.0: **Abbreviations and Acronyms** – Lists the abbreviations and acronyms used.

The full list of attachments in support of **this Report** is as follows:

Attachment 1: Government Submissions and IESC Advice Reconciliation Tables

Attachment 2: Hydrogeological Peer Review Reconciliation Tables and Final Peer Review Letter

Attachment 3: Figures

Attachment 4: Groundwater Monitoring Locations, Installation Details, Landholder Bore Locations and Census Details, and North-East / East Drill Hole Geological and Geophysical Logs (CQCPL, 2019)

Attachment 5: Transient Electromagnetic Survey Report (Groundwater Imaging, 2019)

Attachment 6: Fluvial Geomorphology Assessment (Fluvial Systems Pty Ltd, 2020)

Attachment 7: Targeted Groundwater Investigation Results – Aquifer Testing (AMEC, 2019)

Attachment 8: Groundwater Datasets – Hydrographs

Attachment 9: Laboratory Core Permeability and Porosity Testwork Results (GES, 2020)

Attachment 10: Numerical Groundwater Model Review of Confidence Level Classification

Attachment 11: Uncertainty Analysis Outputs (HydroAlgorithmics, 2020)

Attachment 12: Pilot Point Properties Spatial Plots

Attachment 13: Model Layer Head Plots – End of Calibration

Attachment 14: Model Layer Spatial Drawdown Plots – During Mining

Attachment 15: Model Layer Head Plots – During and Post-Mining

Attachment 16: Parameter Identifiability Spatial Plots

Attachment 17: Presentation Slides to DES on 20 November 2019 and 28 February 2020

Attachment 18: Additional Parameter Analysis – Key Model Outputs

Attachment 19: Endnotes

2.0 REGULATORY FRAMEWORK

The regulatory framework for groundwater-related matters in Australia, and relevantly Qld, has undergone substantial changes in the last five years. The respective framework, streamlining and integration of the State and Commonwealth legislative requirements, are discussed below.

2.1 QUEENSLAND REGULATORY FRAMEWORK

Key environmental planning and water-related legislation (and relevant subordinates) in Qld include:

- *State Development and Public Works Organisation Act 1971* (SDPWO Act);
- *Environmental Protection Act 1994* (EP Act);
- *Water Act 2000*;
- *Marine Parks Act 2004*;
- *Planning Act 2016*;
- *Water Regulation 2016*;
- *Environmental Protection Regulation 2019*[10]; and
- *Environmental Protection (Water and Wetland Biodiversity) Policy 2019*[11].

In 2014, economic development in regional Qld was encouraged through the introduction of the *Water Reform and Other Legislation Amendment Act 2014* (WROLA Act) as well as the *State Development, Infrastructure and Planning (Red Tape Reduction) and Other Legislation Amendment Act 2014*. In 2016, changes to the WROLA Act were subsequently made after the introduction of the *Water Legislation Amendment Bill 2015* and the *Environmental Protection (Underground Water Management) and Other Legislation Amendment Act 2016* (Underground Water Management Act). The Underground Water Management Act relevantly amended both the EP Act and *Water Act 2000,* commencing on 6 December 2016.

The CQC Project is not a declared 'coordinated project' under the SDPWO Act and therefore the Qld Coordinator-General does not coordinate the environmental impact assessment process. The DES is responsible for the administration, coordination and delivery of EIS assessments under the EP Act and, relevant to the CQC Project, is discussed in **Section 2.1.1**. Thus, matters relating to the *Planning Act 2016* (e.g. buildings, civil infrastructure and vegetation clearing) pertaining to the coordination and integration of planning at the local, regional and State levels are not considered further herein. Other relevant legislation listed above is discussed further in the following sub-sections.

2.1.1 Environmental Protection Act 1994 and Environmental Protection Regulation 2019

The object of the Qld *Environmental Protection Act 1994* (EP Act), and subordinate *Environmental Protection Regulation 2019*, is to protect Queensland's environment while allowing for development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends (ecologically sustainable development). Under the EP Act, an EIS assessment is required as part of the application for an EA to undertake an environmentally relevant activity.

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[10] The *Environmental Protection Regulation 2008* was replaced on 1 September 2019.

[11] The *Environmental Protection (Water) Policy 2009* was replaced on 1 September 2019.

The EIS process assesses the potential environmental impact of development, and describes how impacts can be avoided, minimised and/or managed. The EIS also informs subsequent approval decisions under the EP Act and other relevant legislation, including the *Water Act, 2000* discussed in **Section 2.1.2**.

In accordance with the EP Act, the Final TOR for the CQC Project were issued by the then DEHP on 4 August 2017 (State of Queensland, 2017). A reconciliation against the groundwater-related requirements of the Final TOR and how each will be considered in **this Report** is presented in **Table 1-1**.

Upon commencement of the Underground Water Management Act on 6 December 2016, minimum reporting requirements for groundwater impact assessments were outlined within the *Guideline Requirements for site-specific and amendment applications – underground water rights* relating to Section 126A of the EP Act. A summary of the relevant guideline requirements and where each will be considered in **this Report** is presented in **Table 2-1**.

Table 2-1
Requirements for Site-Specific and Amendment Applications – Underground Water Rights

Part	Specific Requirement	How Considered/ Addressed
Part A	A statement that the applicant proposes to exercise underground water rights.	Section 2.1.2
Part B	A description of the area/s in which underground water rights are proposed to be exercised.	ML 80187 (Section 8.0)
Part C	A description of the aquifer/s affected or likely to be affected. • Aquifer type (confined, unconfined, fractured etc). • Geology/stratigraphy for each aquifer. • Depth to and thickness of the aquifers. • Physical integrity of the aquifer, fluvial processes and morphology. • Depth to water level and seasonal changes in levels. • Hydrogeological cross sections. • Maps (spatial extent).	Sections 4.0 and 5.0
Part D	An analysis of the movement of underground water to and from the aquifer. • Inputs (i.e. recharge) and outputs (i.e. baseflow and abstraction). • Underground water elevations (i.e. mapped groundwater flow directions). • Connectivity between aquifers and hydraulic properties. • Preferential flow pathways (i.e. faults). • Springs.	Sections 5.0, 6.0, and 7.0
Part E	A description of the area of the aquifer where the water level is predicted to decline because of the exercise of underground water rights. Predictions should: • Be made for the life of the resource project and for post resource tenure closure. • Be made about the timing, spatial extent and magnitude of maximum water level declines in affected aquifers. • Be made about the timing and magnitude of groundwater level equilibrium in affected aquifers. Produce potentiometric contour maps showing maximum predicted water level decline for each affected aquifer. Modelling methodology, including: • Model type (e.g. numerical or analytical). • Modelling platform. • Model inputs. • Model boundary conditions. • Model assumptions and limitations. • Sensitivity analysis and calibration results.	Sections 6.0, 7.0, 8.0 and 9.0
Part F	The predicted quantities of water to be taken or interfered with because of the exercise of underground water rights. Details on the methodology used for measuring extraction volumes and developing the extraction schedule.	Sections 8.1, 8.3, 8.4, 8.5 and 10.1

Table 2-1 (Continued)
Requirements for Site-Specific and Amendment Applications – Underground Water Rights

Part	Specific Requirement	How Considered/ Addressed
Part G	Information on predicted impacts to the quality of groundwater that will, or may, happen because of the exercise of underground water rights. Identify the quality of the groundwater prior to the resource activity commencing. Explain the variation of chemical concentrations as a result of chemical reactions over the life of the project due to the exercise of underground water rights (i.e. changes in salinity and concentration of dissolved gas). Estimate extent and likelihood of groundwater quality impacts, with justification based on potential sources of contamination.	Sections 4.5, 5.5, 9.2, 10.1 and 10.3
Part H	Identifying and describing environmental values: • Information on the environmental values that will, or may, be affected by the exercise of underground water rights. • Describe and define environmental value of aquifers, presenting available raw data used. Document groundwater use, including details on operating bores within the areas predicted to be affected by the exercise of underground water rights. Nature and extent of the impacts on the environmental values (risk assessment): • The magnitude, relative size or actual extent of any impact in relation to the environmental value being affected. • The vulnerability or resilience of the environmental value (severity and duration). Uncertainty of impacts and any assumptions. Surface subsidence impacts.	Sections 5.0, 6.2, 8.3, 8.11, 8.12 and 9.3
Part I	Information on strategies for avoiding, mitigating or managing the predicted impacts on the environmental values or predicted impacts on the quality of groundwater. Strategies for avoiding, mitigating and managing the predicted impacts on both environmental values and predicted changes in groundwater quality should include: • Objectives which define the outcomes that are intended to be achieved (i.e. avoiding, mitigating and managing the predicted impacts) and a description of unavoidable impacts to environmental values. • Measures (specific methods/procedures/tools) to be implemented to demonstrate how the objectives will be achieved. • Indicators relevant to protection of the environmental values (i.e. indicators are the values that are to be measured to gauge whether the objectives are being achieved and are used to are to be used in auditing the performance of measures). • A program for monitoring the indicators (see EP Act Guideline for requirements). • A reporting program which includes triggers for the review of the strategies, and identifies additional data, assessment, analysis and reporting requirements.	Sections 9.0 and 10.0

2.1.2 Water Act 2000 and Water Regulation 2016

The *Water Act 2000*, and subordinate *Water Regulation 2016*, is the primary legislation regulating groundwater resources in Qld with the purpose to *'advance sustainable management and efficient use of water resources by establishing a system for planning, allocation and use of water.'*

Relevant consequences of the Underground Water Management Act when introduced in 2016, and amendments to the *Water Act 2000*, have since resulted in:

- the need for applicants to quantify and be licenced for the direct take of 'associated water';
- a greater emphasis on baseline data collection for environmental assessments; and
- ongoing verification, updating and reporting (via Underground Water Impact Reports [UWIRs]) of groundwater impact predictions.

Each of the above are considered in this Report and are discussed in **Sections 8.4 and 10.4**, **Sections 5.0 and 10.1**, and **Sections 10.7 and 10.9**, respectively.

A framework of catchment-specific Water Plans has been developed under the *Water Act 2000* in Qld, however a Water Plan has not been established for the Styx Surface Water Basin and therefore does not apply to the CQC Project. Nevertheless, it is recognised that Water Plan (Fitzroy Basin) 2011 is relevant to the adjacent catchments to the west and south of the Styx Surface Water Basin (**Figure 2-1**).

As part of the CQC Project, it is understood that the proponent is proposing to exercise underground water rights during the period in which resource activities would be carried out at ML 80187 and ML 700022 and is discussed further in **Section 10.4**.

Office of Groundwater Impact Assessment (OGIA)

The OGIA is an independent entity established under the *Water Act 2000* by the Qld Government. The OGIA provides advice on matters relating to groundwater impacts from resource development to the DES, maintains a database of information, and since the introduction of the Underground Water Management Act in 2016, their role was expanded to include relevant mining development (in addition to petroleum and gas).

The OGIA core functions are to[i]:

- undertake evidence-based independent scientific assessment of cumulative groundwater impacts from resource operations;
- set management arrangements within the cumulative management areas; and
- assign statutory responsibilities to tenure holders for the implementation of management strategies within cumulative management areas.

Relevantly, a cumulative management area has not been established in the Styx Basin, and therefore the OGIA's current role in relation to the CQC Project is an advisory role to DES only.

2.1.3 Environmental Protection (Water and Wetland) Policy 2019

The *Environmental Protection (Water and Wetland Biodiversity) Policy 2019* replaced the *Environmental Protection (Water) Policy 2009* upon its expiration date (1 September 2019) in accordance with section 54 of the *Statutory Instruments Act 1992*. Nevertheless, the environmental values (EVs) and water quality objectives (WQOs) for Capricorn Curtis Coast waters that were finalised in November 2014 continue to apply and are now included in Schedule 1 of the *Environmental Protection (Water and Wetland Biodiversity) Policy 2019* (**Figure 2-2**). Whilst the *Environmental Protection (Water and Wetland Biodiversity) Policy 2019* is substantially similar to the superseded policy, a key change was the relocation of the 'Map of referable wetlands' from the *Environmental Protection Regulation 2008* and renaming as the 'Map of Queensland wetland environmental values'. Further discussion relating to EVs and WQOs of relevance to the CQC Project is provided in **Section 6.2**, including consideration of the *Great Barrier Reef Basins End-of-Basin Load Water Quality Objectives* (DES, 2019).

It is noted that as part of the water quality planning process under the former *Environmental Protection (Water) Policy 2009,* the Qld Department of Science, Information Technology and Innovation (DSITI) released for consultation the *Draft Environmental Values and Water Quality Guidelines: Fitzroy Basin Fresh, Estuarine and Marine Waters, including Keppel Bay* (DSITI, March 2017) for surface waters, and the DES (Water Planning Ecology, Science Division) released for consultation the *Draft Regional Groundwater Chemistry Zones: Fitzroy-Capricorn-Curtis Coast and Burdekin-Haughton-Don Regions Summary and Results* (McNeil, *et al*., 2018) for groundwater. Each of the consultation draft reports are considered in **Section 6.2**.

2.1.4 Marine Parks Act 2004

Schedule 2 of the *Marine Parks (Great Barrier Reef Coast) Zoning Plan 2004*[ii] under the Qld *Marine Parks Act 2004* defines the General Use Zone at the mouth of the Styx River as follows:

> ***11 QI GU-22-14 Styx River***
> *The part of the Styx River that is within the marine park and upstream of the following line—*
> *• from the most northern point of Charon Point at H.A.T.*
> *Note—The most northern point of Charon Point at H.A.T. is approximately latitude 22º22.916' south, longitude 149º48.433' east.*
> *• then north-westerly along a geodesic to the most eastern point of Rosewood Island at H.A.T.*
> *• then westerly along the relevant mangrove line to the most north-western point of Rosewood Island at H.A.T.*
> *Note—The most north-western point of Rosewood Island at H.A.T. is approximately at latitude 22º21.363' south, longitude 149º42.786' east.*

The extent of the General Use Zone is described in **Section 3.5.1** is, at its nearest point, generally coincidental with the boundary defined by the Broad Sound Fish Habitat Area (Plan FHA-047).

2.2 COMMONWEALTH REGULATORY FRAMEWORK

2.2.1 Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act, 1999* (Commonwealth) (EPBC Act) is administered by the Department of the Environment and Energy (DEE) and is the Australian Government's centrepiece of environmental legislation to provide a regulatory framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places; defined in the EPBC Act as Matters of National Environmental Significance (MNES).

On 3 February 2017, a decision was made under Section 75 of the EPBC Act that the proposed action for the Styx Coal Project, Central Qld (EPBC 2016/7851) is a Controlled Action and will require assessment and approval under the EPBC Act before it can proceed.

The Qld Government's EIS process has been accredited for the assessment under Part 8 of the EPBC Act in accordance with the Bilateral Agreement between the Commonwealth of Australia and the State of Queensland (dated 18 December 2014). As stipulated in the Final TOR issued by the then DEHP on 4 August 2017 (State of Queensland, 2017), the CQC Project will be assessed under the Bilateral Agreement using the EIS prepared under the EP Act (**Section 2.1.1**).

Relevant controlling provisions under the EPBC Act for the Styx Coal Project, Central Qld (EPBC 2016/7851) include:

- World Heritage properties (Sections 12 & 15A);
- National Heritage places (Sections 15B & 15C);
- Listed threatened species and communities (Sections 18 & 18A);
- Listed migratory species (Sections 20 & 20A);
- Great Barrier Reef Marine Park (Sections 24B & 24C); and
- A water resource, in relation to coal seam gas development and large coal mining development (Section 24D &24E).

Whilst only one impact assessment is required, the documentation is reviewed separately by the Qld and Commonwealth Government departments, and in accordance with Appendix 3 of the Final TOR under the EP Act, the assessment of the potential impacts, mitigation measures and any offsets for residual significant impacts must be dealt with in a stand-alone section of the EIS that fully addresses the matters relevant to the controlling provisions. Such matters are discussed separately in **Section 11.0**, and include reference to the following guidelines published by the Australian Government:

- *Matters of National Environmental Significance – Significant Impact Guidelines 1.1 Environment Protection and Biodiversity Conservation Act 1999* (Department of the Environment, 2013); and
- *Significant Impact Guidelines 1.3: Coal Seam Gas and Large Coal Mining Developments – Impacts on Water Resources* (Department of the Environment, 2013).

The stand-alone chapter/section is presented in SEIS Version 3 prepared by Orange Environmental Pty Ltd (2020) and **this Report** has been specifically tailored to support.

Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) and Office of Water Science (OWS)

The IESC is a statutory body under the EPBC Act that provides scientific advice to the Commonwealth Environment Minister and relevant Qld Ministers. The Office of Water Science (OWS) provides secretariat support to the IESC, as well as technical support to assist in its consideration of requests for advice on development proposals. Guidelines have been developed in order to assist the IESC in reviewing coal seam gas (CSG) or large coal mining development proposals that are likely to have significant impacts on water resources. Relevantly, specific advice from the IESC has been sought on two (2) separate occasions for the CQC Project, *viz*.:

- **1 November 2017:** by the DEE and then DEHP at the Assessment Stage, based on a review of the *Central Queensland Coal Project Environmental Impact Statement* (CDM Smith, 2017a), with Advice to the Decision Maker (IESC 2017-091) issued on 15 December 2017; and
- **19 June 2018:** by the DEE and DES at the Assessment Stage, based on a review of the *Central Queensland Coal Project Supplementary Environmental Impact Statement May 2018* (CDM Smith, 2018c), with the Advice to the Decision Maker (IESC 2018-094) issued on 31 July 2018.

Each of the matters raised in IESC 2018-094 (including where relevant, matters raised in the previous IESC 2017-091) are provided in **Attachment 1 (Table A1-4)**.

It is however noted that during and since the aforementioned reviews, the IESC has published the *Information Guidelines for proponents preparing coal seam gas and large coal mining development proposals* (dated May 2018) (Information Guidelines), and subsequently finalised supporting explanatory notes, including:

- *Information Guidelines Explanatory Note: Uncertainty Analysis – Guidance for Groundwater Modelling within a Risk Management Framework (dated 17 December 2018)*;
- *Information Guidelines Explanatory Note: Assessing Groundwater-Dependent Ecosystems* (dated 8 March 2019); and
- *Information Guidelines Explanatory Note: Deriving Site-Specific Guideline Values for Physico-chemical Parameters and Toxicants* (dated 7 June 2019).

A checklist against the requirements of the IESC Information Guidelines is presented in **Section 11.3 (Table 11-2)**, with details on where aspects are addressed and documented within **this Report** or otherwise considered by others.

Relevantly, the fatal flaw checklists published in the IESC's *Information Guidelines Explanatory Note: Uncertainty Analysis – Guidance for Groundwater Modelling within a Risk Management Framework* (dated 17 December 2018) has also been specifically considered and a reconciliation table included in **Attachment 1** (**Table A1-5**).

2.2.2 Great Barrier Reef Marine Park Act 1975

The Marine National Park Zone MNP-21-1146 (Broad Sound area including the Bedwell Group, Wild Duck and Bamborough Island) is defined in Part 6 of the Great Barrier Reef Marine Park Zoning Plan 2003 (GBRMPA, 2004).

The nearest point of the Marine National Park Zone MNP-21-1146 to the Qld coastline is north of Charon Point and Rosewood Island. The nearest Habitat Protection Zone is further east, at Island Bluff near Thirsty Sound. The nearest Conservation Park Zone and Species Conservation (Dugong Protection) boundary is again further north, near Clairview (CP-22-4096).

Section 54 of the *Great Barrier Reef Marine Park Act 1975* requires that the Great Barrier Reef Marine Park Authority (GBRMPA) prepare an Outlook Report every 5 years, with the latest published in 2019 (GBRMPA, 2019)[iii]. The Outlook Report recognises the mid-term review of the *Reef 2050 Long-Term Sustainability Plan* in July 2018 following Cyclone Debbie in 2017 and coral bleaching events (Commonwealth of Australia, 2018).

3.0 HYDROLOGICAL AND LANDSCAPE SETTING

3.1 CLIMATE

Historical climate data is presented and discussed in detail in Chapter 4 of the SEIS. A summary of the earlier work undertaken by others, and relevant outcomes supplemented with additional information for the purposes of this groundwater modelling and assessment is provided below.

Recorded climate data at several Bureau of Meteorology (BOM) weather stations in the vicinity of the CQC Project, Styx River catchment and broader Styx Surface Water Basin, have been considered, including (**Figure 3-1**):

- 033065 (open) – St Lawrence Post Office [1870-2019] (Lat 22.35°S; Long 149.54°E; Elevation 17.77 m);
- 033211 (closed) – Tooloombah [1890-2001] (Lat 22.73°S; Long 149.54°E; Elevation: 80 m);
- 033057 (closed) – Ogmore Post Office [1934-1990] (Lat 22.62°S; Long 149.66°E; Elevation: 20 m);
- 033189 (open) – Strathmuir [1941-2019] (Lat 22.71°S; Long 149.73°E; Elevation: 40 m);
- 033187 (closed) – Hill End [1967-1973] (Lat 22.52°S; Long 149.73°E; Elevation: N/A);
- 033190 (closed) – Montrose [1973-1979] (Lat 22.63°S; Long 149.52°E; Elevation: N/A);
- 033202 (closed) – Charon's Ferry [1973-2003] (Lat 22.57°S; Long 149.67°E; Elevation: N/A); and
- 033111 (open) – Marlborough Helipad TM [2001-2019] (Lat 22.82°S; Long 149.89°E; Elevation: 107 m).

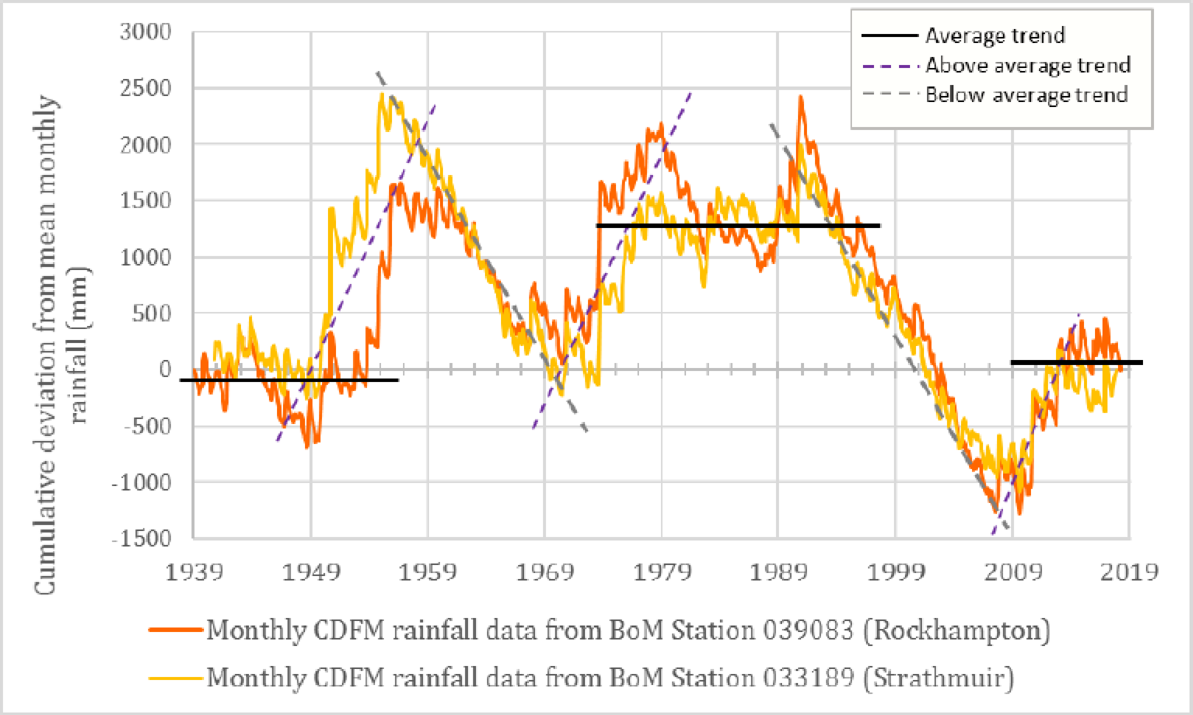
Available rainfall, evaporation, evapotranspiration and temperature records are presented where relevant, including consideration of seasonal and historical trends. Comparisons are also made with the BOM weather station at Rockhampton Aero (039083).

An automatic weather station (AWS) (ML1) has been established at the CQC Project at Mamelon Station (**Figure 3-1**). The AWS records rainfall (and rainfall intensity), wind speed, wind direction, humidity, air temperature and solar radiation. Data is stored and downloaded periodically to provide 10 minute, hourly and daily summaries.

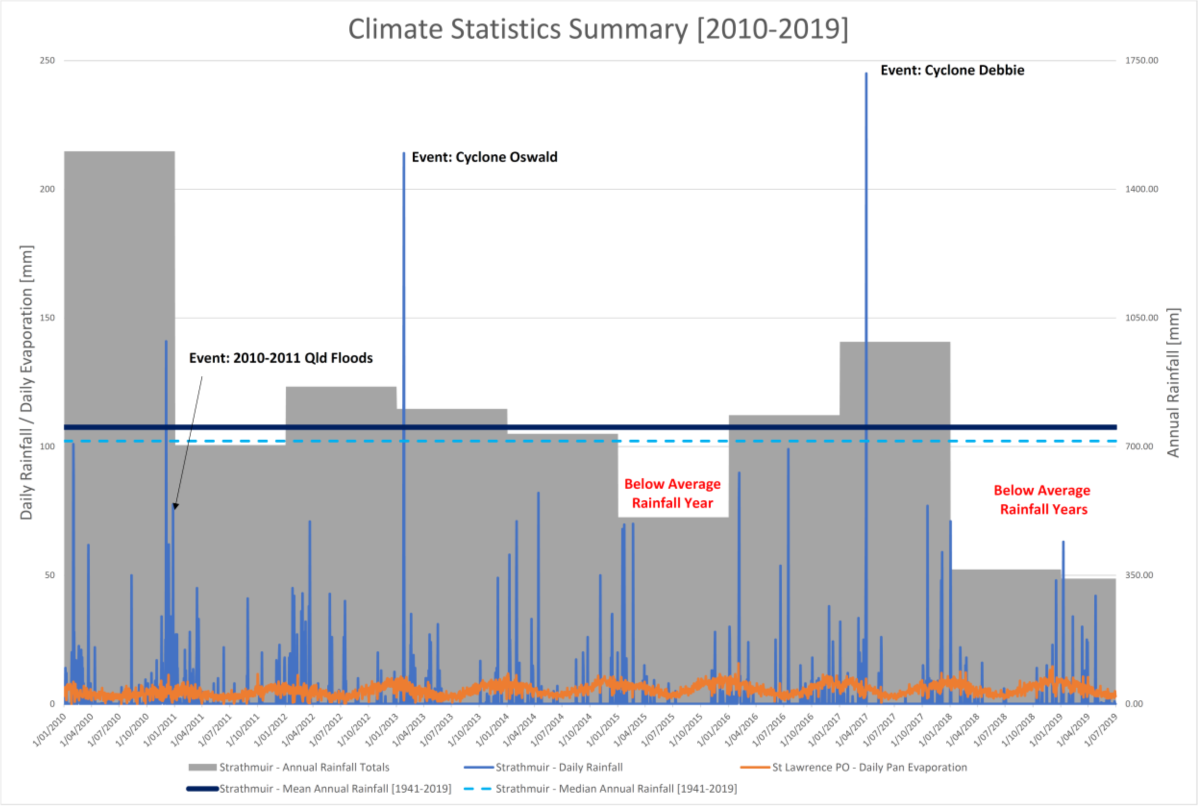
3.1.1 Rainfall and Historical Trends (including Cumulative Deviation from Mean)

Long-term rainfall datasets available at Strathmuir (033189) and Rockhampton Aero (039083) are presented in **Graph 3-1** as a cumulative departure from mean (CDFM) curve to show the accumulated difference between actual rainfall and the long-term average. The CDFM curve importantly provides an indication of historical trends and general water availability (i.e. soil water, surface water and groundwater). Relevantly the CDFM curve demonstrates relatively steady climatic conditions in the past decade (since the 2010-11 Qld floods), however it is noted that more recently (2018 and the 1st half of 2019) below average rainfall conditions have been experienced and is shown on **Graph 3-2** for the period 2010-2019.

Rainfall data has been recorded locally at Strathmuir (BOM Station 033189) since 1941. The climate statistics for the full period of record show that the mean annual rainfall is **752.1 mm**, with a median of **715.1 mm**. The median annual rainfall is also comparable to historical rainfall datasets available at Tooloombah (033211) which recorded **719.7 mm** between 1890 and 2001.



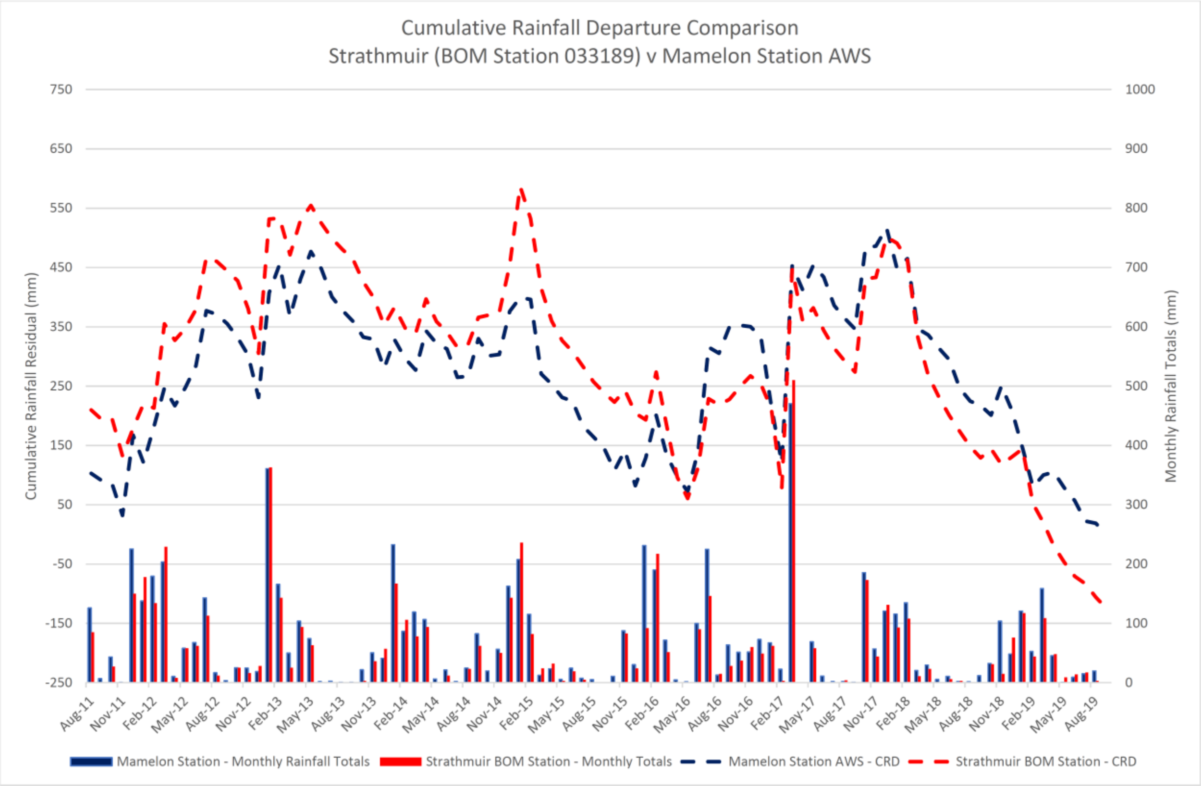
Graph 3-1
Long-term Rainfall Trend - Cumulative Departure from Mean Curve
[*Source: Figure 4.2 in CDM Smith, 2018e*]



Graph 3-2
Climate Statistics Summary [2010-2019] – Strathmuir [Rainfall] and St Lawrence PO [Evaporation]

Seasonally, the historical climate summaries show a distinct wet season with the highest rainfall occurring during the summer months (highest monthly average in February [135 mm at Strathmuir]) and lowest rainfall periods in early spring (lowest monthly average in September [16 mm at Strathmuir]).

Long-term (including synthetic) rainfall data sourced from the gridded dataset produced by the Scientific Information for Land Owners (SILO) at the CQC Project (Lat 22.7°S; Long 149.65°E) indicated good agreement and consistent trends. A graphical comparison of the available monthly rainfall datasets at the Mamelon Station AWS from 2011 to 2019 with the Strathmuir (BOM Station 033189) also demonstrates generally consistent rainfall totals and trends (**Graph 3-3**).



Graph 3-3
Cumulative Rainfall Departure Comparison [2011-2019] – Mamelon Station AWS and Strathmuir

Regionally, the datasets available at St Lawrence Post Office (north and beyond the Styx River catchment) show higher average rainfall than the available BOM stations nearer to the CQC Project and Mamelon Station AWS within the Styx River catchment.

Consideration of the available rainfall datasets, corresponding with the extended groundwater model transient calibration period (2010-2019), is provided in **Sections 5.4.2 and 7.7.4**.

Further discussion regarding the flood (recharge) events resulting from the higher intensity rainfall (including tropical cyclones Tasha [during 2010-2011 flood event], Oswald [during January 2013] and Debbie [during March 2017]) is provided in **Sections 3.3 and 7.5.4**.

3.1.2 Evaporation and Actual Evapotranspiration

Average monthly and average annual evaporation datasets across Australia are made available by the Australian Government BOM.

Evaporation is defined as follows:

> *Evaporation is the amount of water which evaporates from an open pan called a Class A evaporation pan. The rate of evaporation depends on factors such as cloudiness, air temperature and wind speed. Measurements are made by the addition or subtraction of a known amount of water, which then tells us how much water has evaporated from the pan.*

The seasonal distribution of average pan evaporation across Qld is shown on **Figure 3-2**, ranging from approximately 315 mm during winter to 535 mm during summer for ML 80187 and surrounds.

The St Lawrence Post Office (BOM Station 033065), located approximately 40 km north-west of the CQC Project, has recorded daily evaporation data since 1972. For the purposes of comparison for the equivalent groundwater model calibration period between 2010-2019, recorded annual pan evaporation at the St Lawrence Post Office (sourced from SILO) is presented in **Table 3-1**, coupled with recorded rainfall datasets at Strathmuir (BOM Station 033189). The daily records for the period 2010-2019 are also shown graphically on **Graph 3-2**.

Table 3-1
Summary of Relevant Annual Rainfall and Pan Evaporation Datasets (2010-2019)

Year	Rainfall (mm) Strathmuir (BOM Station 033189)	Pan Evaporation (mm) St Lawrence Post Office (BOM Station 033065)
2010	1,503.3	1,404.2
2011	704.1	1,542.2
2012	863.0	1,722.6
2013	802.6	1,924.1
2014	735.1	2,140.0
2015	508.1	2,266.6
2016	785.5	2,167.2
2017	985.0	2,109.8
2018	366.0	2,187.0
2019*	340.9	1,015.6

* To 30 June 2019.

As shown by the climate statistics in **Table 3-1**, the recorded annual average pan evaporation is often two to three times greater than the average annual rainfall for the region.

Notably, daily evaporation (mm) has also been recorded at the Mamelon Station AWS since 2011, with annual average evaporation for the complete calendar year records from 2012 to 2018 ranging between approximately 700 mm and 1,115 mm per annum.

Therefore, more relevantly for the purposes of groundwater modelling and assessment, the annual average areal actual evapotranspiration, as estimated by the BOM for the period 1961-1990 is used. Evapotranspiration (or ET) is a collective term for the transfer of water, as water vapour, to the atmosphere from both vegetated and unvegetated surfaces. It is affected by climate, availability of water and vegetation.

The areal actual ET is defined as[iv]:

> *…the actual ET that would take place under the prevailing soil water condition, from an area large enough such that the effects of any upwind boundary transitions are negligible, and local variations are integrated to an areal average.*

For example, this represents the evapotranspiration which would occur over a large area of land under average rainfall conditions. It is noted that, unlike the areal and point potential evapotranspiration, there is not an assumed unlimited water supply.

Based on the BOM estimates for 1961-1990, the average areal actual evapotranspiration (annual) for the CQC Project and surrounds is estimated to be approximately 715 mm (**Figure 3-3**), generally equivalent to the recorded median rainfall at Strathmuir between 1941-2019.

The specific application of evapotranspiration in the groundwater model (i.e. actual ET), including variable extinction depths based on geology (e.g. unconsolidated sediments) and vegetation cover considering maximum rooting depths of vegetation types (Canadell *et al.*, 1996 and Shah *et al*., 2007) for the purposes of this groundwater assessment, is discussed separately in **Section 7.5.5**.

3.1.3 Temperature

The St Lawrence Post Office (BOM Station 033065) recorded air temperature from 1938 to 2012 (a 73-year period), with mean annual minimum and maximum temperatures recorded of 17.4 degrees Celsius (ºC) and 28.4ºC, respectively. The recorded mean monthly temperatures (minimum-maximum) at the weather station for the period are presented in **Table 3-2**.

Table 3-2
Recorded Mean Monthly Temperatures [Minimum-Maximum] (ºC) at St Lawrence Post Office (Station 033065) (1938-2012)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Summer		Autumn			Winter			Spring			Summer	
22.5 - 31.7	22.5 - 31.4	21.1 - 30.9	18.4 - 29.3	15.1 - 26.7	12.2 - 24.3	10.9 - 23.8	11.8 - 25.0	14.4 - 27.0	17.7 - 28.9	20.2 - 30.4	21.7 - 31.5	17.4 - 28.4

Source: http://www.bom.gov.au/climate/averages/tables/cw_033065.shtml.

Air temperatures vary on a seasonal basis with the lowest mean monthly minimums at approximately 11-12ºC in winter and the highest mean monthly maximums at approximately 31-32ºC in summer.

3.2 TOPOGRAPHY, WATERCOURSES AND DRAINAGE FEATURES

Contemporary Qld Government documentation[v] broadly defines the Styx Surface Water Basin as comprising several coastal catchments and sub-catchments which drain to the Broad Sound and adjoining estuarine systems including:

- Clairview Creek catchment, including:
    - Cattle Creek sub-catchment;
- St Lawrence Creek catchment;
- Waverley Creek catchment, including:
    - Home Creek and Amity Creek sub-catchments;

- Wellington Creek catchment, including:
    - Stoodleigh Creek sub-catchment; and
- Styx River catchment, including:
    - Granite Creek, Montrose Creek; Tooloombah Creek; and Deep Creek sub-catchments.

The CQC Project is located predominantly within the Deep Creek sub-catchment, within the Styx River catchment, of the broader Styx Surface Water Basin. The Styx Surface Water Basin is generally consistent with Basin 127 in Australia's River Basins 1997 (Geoscience Australia, 2004) (**Section 6.2**).

The catchments and sub-catchments of the Styx Surface Water Basin are topographically defined generally by the following:

- in the north-west (Clairview Creek catchment) by:
    - Mt Upright (266 mAHD); Fort Arthur (454 mAHD); and Mt Edward (171 mAHD);
- in the north-west (St Lawrence Creek catchment) by:
    - The Peaks; Connors Hump (475 mAHD) (in the Glencoe State Forest); Evelyn Peak (471 mAHD); and Catherine Peak (576 mAHD);
- in the west (Waverley Creek catchment) by:
    - Mt St Catherine (573 mAHD); Mt Macartney (402 mAHD); Mt Buffalo (500 mAHD); and Prospect Hill (160 mAHD);
- in the east and south-east (Wellington Creek catchment) by:
    - Cliff Peak (305 mAHD); Mt Phillip (393 mAHD); and Mt Wellington (528 mAHD);
- in the west (Granite Creek/Montrose Creek sub-catchments) by:
    - Broadsound Range; Mt Buffalo (500 mAHD) (and Mount Buffalo State Forest and Burwood Nature Refuge); Campbell Range; Mt Lorne (546 mAHD); Mt Michael (562 mAHD); and Mt Sarsfield (502 mAHD); and
- in the south-west (Tooloombah Creek sub-catchment) by:
    - Broadsound Range; Rocky Peak (460 mAHD); Mt Larry (505 mAHD); Gilnorchie Peak (220 mAHD); Fort St John; The Sisters; Mt Brunswick (165 mAHD); Mt Mamelon (158 mAHD); and Mt Bison (260 mAHD).

The southern extent of the Deep Creek sub-catchment, at the headwaters of the Styx River catchment, comprises elevated and hilly topography ranging up to approximately 200 mAHD.

Within the mining tenements for the CQC Project, the topography typically ranges from approximately 11.4 mAHD to 43.8 mAHD and classified as predominately flat or undulating (CDM Smith, 2018e).

Detailed topographic datasets available for the CQC Project area and surrounds have been provided by CQCPL / Orange Environmental Pty Ltd including:

- Light Detection and Ranging (LiDAR) survey data (high-resolution [3 m]); and
- Digital Elevation Model (25 m and 50 m).

The LiDAR survey data was captured by airborne laser scanning from a fixed wing aircraft on 17 June 2011 by Vekta Pty Ltd (2011) with related field survey performed on 7 June 2011.

Target survey accuracies were +/- 0.15 m (vertical) and +/- 0.45 m (horizontal) in areas of clear and open terrain. Base data was obtained from the permanent survey marker (PSM) 133415 in Ogmore and used as the datum at:

- Easting: 773261.937
- Northing: 7496082.509
- Height: 20.138 mAHD

Vekta Pty Ltd surveyors performed a number of validation surveys evenly distributed throughout the survey domain (**Figure 3-4**) to confirm that overall ground surface accuracies were within target tolerances.

An independent survey of borehole locations was also provided by Mr Dave Beatty (surveyor) for validation. The minimum and maximum vertical differences were reported as follows (Vekta Pty Ltd, 2011):

- Minimum ΔZ = -0.259 m
- Maximum ΔZ = +0.547 m

Digital elevation model data beyond the LiDAR survey area was merged and infilled within the groundwater model domain (**Section 7.4**) using Shuttle Radar Topography Mission (SRTM) derived information where available from Geoscience Australia.

Finally, on-ground survey measurements were also taken at key reference points at the CQC Project and surrounds by Walton Bore Geophysics (WBG) on behalf of CQCPL in 2020 and is considered further in **Section 8.12.3**, including subsequent detailed survey reported in the *CQC Surface Water Monitoring Survey Report* (CQCPL, 2020a) and updates/verification by CCS Surveys Pty Ltd (2020).

3.2.1 Styx River Catchment

The Styx River catchment[12] drains a total land area of approximately 1,608.1 km^2 and comprises three main hydrological sub-catchments which approximately define the upstream limit (Tooloombah Creek near Ogmore, downstream of the Deep Creek confluence)[13] and downstream limit (Granite Creek/Montrose Creek confluence) of the named Styx River before draining to the estuarine systems of the Broad Sound. Other hydrological sub-catchments which drain directly to the estuarine systems of the Broad Sound (at the mouth of the Styx River) include the Wellington Creek (including Stoodleigh Creek) catchment.

The Broad Sound Declared Fish Habitat Area (FHA-047) (**Figure 3-5**) consists of 170,394 ha of the Broad Sound and adjoining estuarine systems.

Its boundary is defined at the mouth of the Styx River by the cadastral boundary (at a point 20 m from and parallel to) the North Coast Line railway crossing of the Styx River (immediately downstream of the Granite Creek/Montrose Creek confluence with the Styx River), and therefore for the purposes of this groundwater assessment have been consistently defined and assessed accordingly. Further details of the Broad Sound Declared Fish Habitat Area (FHA-047) are provided in **Section 3.5.1**.

A breakdown of sub-catchment areas of the Styx River catchment is presented in **Table 3-3**. The corresponding catchments and sub-catchments are shown on **Figure 3-6** and described in the following sub-sections.

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[12] It is noted that the Qld Government Wetland*Info* register refers to the *Styx drainage basin* as comprising the Styx River Catchment, Waverley Creek Catchment and St Lawrence Creek Catchment, with a total area of 3,013.4 km^2. Each of these catchments separately drain to the Broad Sound.

[13] It is noted that whilst the downstream limit defined by the *Water Act 2000* is at Ogmore, for the purposes of assessment, the Styx River reach has been assessed as shown on **Figure 3-6**.

Table 3-3
Breakdown of Styx River Catchment Areas and Relative Comparisons

Catchment [Sub-Catchment]	Area (km^2)	% of Styx River Catchment	% of Total Styx Drainage Basin^	% of Total Cumulative Catchment Reporting in Styx Drainage Basin at Styx River Confluence
Styx River (Mouth)	1,608.1	100%	53.4%	53.4%
[Broad Sound FHA Lower Catchments] (including lower parts of Wellington Creek, Stoodleigh Creek, unnamed north-eastern sub-catchments and Styx River estuarine areas)	243.9	15.2%	8.1%	53.4%
[Wellington Creek Catchment] (excluding lower reaches in Broad Sound FHA)	286.7	17.8%	9.5%	45.3%
[Stoodleigh Creek Catchment] (excluding lower reaches in Broad Sound FHA)	70.2	4.4%	2.3%	
[Granite Creek and Montrose Creek Catchments]	277.4	17.3%	9.2%	33.4%
[Styx River Lower Catchment] (including Ogmore [Cedar Creek] and eastern slopes of The Sisters)	51.4	3.2%	1.7%	24.2%
[Tooloombah Creek Catchment]	379.4	23.6%	12.6%	
[Deep Creek Catchment]	299.0	18.6%	9.9%	9.9%

^ Based on the Qld Government Wetland*Info* register total area of 3,013.4 km^2.

As described in **Section 3.4.5**, coal mining and exploration has historically occurred in the Styx River catchment since the late 1800s. Notably, and as considered further for the purposes of the groundwater model calibration, ongoing recovery and cumulative assessment, the extent of historic underground mine workings at the Styx No.1 & No.2, Styx No.3 and Bowman Coal Mine is shown on **Figures 3-12 to 3-17** in the Styx River/Tooloombah Creek lower catchment and Deep Creek sub-catchment. Local tributaries including Cedar Creek, north of the Ogmore, and Fault Gully near Bowman, were also historically undermined (**Figures 3-15[a] and 4-3[a]**).

A discussion of tidal levels in the Styx River reach at Ogmore Road bridge crossing is provided in **Section 3.3.2**. A photograph of the Styx River reach downstream of the bridge crossing in September 2019 (i.e. during the period of extended dry conditions) is shown in **Plate 3-1**.

Site St2 at (immediately downstream of) the Ogmore Road Bridge crossing and upstream of the Broad Sound Declared Fish Habitat Area (FHA-047), is the furthest downstream sampling point (some 8 km downstream[14] of the CQC Project footprint).

These datasets are supplemented with prior periodic surface water monitoring measurements by the Fitzroy Basin Association Inc. (FBA) between January 2008 and March 2012 (Yeats Consulting Engineers, 2012), coincident with the current Site St1, downstream of the CQC Project at the confluence of Deep Creek and Tooloombah Creek.

Surface water quality monitoring datasets in the Styx River catchment since 2011 are presented in CDM Smith (2018e; 2018h; 2018j) and summarised in **Section 3.2.7** (with additional 2019 datasets).

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[14] Along the centreline of the watercourses.

Plate 3-1
Styx River [September 2019] / Downstream of Ogmore Road Bridge Crossing
[*Source: GES, 2019*]

3.2.2 Granite Creek/Montrose Creek Sub-Catchments

The CQC Project is not located in the Granite Creek/Montrose Creek sub-catchments. However, the sub-catchments combine and relevantly drain direct to the lower reach of the Styx River less than 1 km upstream of the Broad Sound Fish Habitat Area (FHA-047) and comprises more than 17% of the total Styx River catchment.

The Granite Creek sub-catchment drains a total area of approximately 153 km^2 and includes the Mount Buffalo State Forest and Burwood Nature Refuge at its headwaters. The Montrose Creek sub-catchment drains a total area of approximately 124 km^2, including the northern slopes of Mount Sarsfield, Mount Lorne and Mount Michael.

The Granite Creek and Montrose Creek sub-catchments are divided by the Campbell Range which extends from the Broadsound Range in the west.

A baseline surface water quality sampling campaign was commenced at Gr1 (**Figure 3-6**) in the Granite Creek sub-catchment in 2011 and results summarised in **Section 3.2.7**. The reference sampling point was located at the Bruce Highway crossing which appears to also be near a property associated with a Fitzroy Basin Association (FBA) project[15].

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[15] Sustainable Agriculture through Innovative Practices in the Fitzroy (FBA, 1 October 2013 – 30 June 2016).

A surface water extraction point exists on Montrose Creek approximately 5 km west of Ogmore. The Montrose Creek Intake is part of the Ogmore Water Supply System which is managed by the Livingstone Shire Council. Non-potable water is pumped directly from the Montrose Creek Weir (a small, 0.5 m high concrete weir, with a storage capacity of approximately 12 megalitres) to four small ground level storage tanks in the Ogmore township and is distributed periodically to residents. The combined reservoir capacity of the Ogmore Water Supply System (in Ogmore) is 88,000 litres[vi].

Photographic plates of Granite Creek and Montrose Creek are provided on **Plates 3-2 to 3-4**.

Plates 3-2 & 3-3
Granite Creek Pool and Riffles [June 2011]
[Source: ALS Water Sciences Group (2011)]

Plate 3-4
Montrose Creek Intake [October 2019] / Approximately 5 km West of Ogmore

3.2.3 Tooloombah Creek Sub-Catchment

The Tooloombah Creek sub-catchment (approximately 379 km^2) comprises several large upper sub-catchments including:

- Mamelon Creek, including local drainage sub-catchments:
    - Kyour Creek; and Oaky Creek;
- Sarsfield Creek;
- Magdalen Creek;
- Gilnorchie Creek;
- Clive Gully;
- Tooloombah Creek North Branch; and
- Tooloombah Creek South Branch.

Only a small area of the CQC Project (in the north-west) is located within the Tooloombah Creek sub-catchment area (**Figure 3-6**).

Further discussion and photographic plates of Tooloombah Creek are presented in **Section 3.3.3**.

3.2.4 Deep Creek Sub-Catchment

The CQC Project is located predominantly in the Deep Creek sub-catchment which drains to Tooloombah Creek. The historic coal mines at Bowman (Styx No.1 State Coal Mine, Styx No.2 State Coal Mine and Bowman Coal Mine [Bowman Coal Mining Syndicate]), are located north-east of the lower reaches in the Deep Creek sub-catchment (**Section 3.4.5**).

The Deep Creek sub-catchment, comprising local drainage sub-catchments of Barrack Creek, Brussels Creek and Brumby Creek, drains the southern areas (approximately 9.9%) of the total Styx Drainage Basin. The Barrack Creek sub-catchment drains a total area of approximately 53 km^2 with its confluence with Deep Creek located directly east of CQC Project. The upper sub-catchments which join Deep Creek upstream of the CQC Project include Brussels Creek (approximately 41 km^2) and Brumby Creek (approximately 32 km^2).

Further discussion and photographic plates of Deep Creek and other drainage features are presented in **Sections 3.3.4 and 3.3.5**.

3.2.5 Wellington Creek Catchment (and Stoodleigh Creek Sub-Catchment)

The Wellington Creek catchment includes several tributaries which drain the western slopes of the ranges from Cliff Peak, Mt Phillip and Mt Wellington to the Bukkulla Conservation Park and Marlborough State Forest, north-west of Marlborough. Named tributaries of Wellington Creek include Ewan Creek, Oaky Creek, Landsborough Creek (including North Branch), Wangraby Creek and Stotts Creek.

Stoodleigh Creek and its tributary Stockyard Creek is a smaller sub-catchment which drain the areas between Ogmore and the Wellington Creek catchment, before joining Wellington Creek at its confluence at the mouth of the Styx River (i.e. within Broad Sound Fish Habitat Area FHA-047). Several other unnamed drainage lines also report directly to the Styx River mouth to the north-east of the Wellington Creek catchment, and for the purposes of this assessment has been collectively considered as a north-eastern sub-catchment area.

The CQC Project is not located in the Wellington Creek catchment, however it is recognised the Wellington Creek catchment (including the north-eastern sub-catchments and Stoodleigh Creek) comprise approximately 37%[16] of the Styx River catchment and drains directly to the Broad Sound Fish Habitat Area (FHA-047).

3.2.6 Clairview Creek, St Lawrence Creek and Waverley Creek Catchments

The CQC Project is not located in either of the Clairview Creek, St Lawrence Creek or Waverley Creek catchments.

For comparative purposes, Amity Creek (in the Waverley Creek catchment) was inspected and two sampling events occurred in 2011-12 (Yeats Consulting Engineers, 2012) and sampling has since been conducted by CQCPL in February 2020. A summary of the results of surface water sampling events are presented in **Section 3.2.7**.

Nevertheless, it is recognised that historic coal exploration and mining activities had commenced in the catchment, and agriculture continues to be a predominant land use, including farmland development projects (e.g. Racecourse Projects). As relevantly stated in the 1:250,000 Geological Series – Explanatory Notes for St Lawrence, Qld (Malone, 1964):

> *St Lawrence Township Area: The occurrence of coal in the St Lawrence area was known before 1889. The Broadsound Coal Company engaged in vigorous campaign between 1889 and 1891. Seven bore holes and at least five shafts were put down in the vicinity of St Lawrence. They were successful in locating coal in a shaft on Waverley Creek, about three and a half miles southeast of St Lawrence. However, an influx of water in June 1891 forced closure of the mine and no production recorded.*

An overview of coal mining and exploration history in the broader Styx River Coalfield is provided in **Section 3.4.5**.

3.2.7 Surface Water Quality and Stream Health

Monitoring of surface water quality and other stream health indicators (including macroinvertebrates, fish and aquatic reptiles) in watercourses and drainage lines has been undertaken within the mining tenements and areas surrounding the CQC Project for over a decade. Several targeted baseline data collection campaigns by CQCPL have occurred within the Styx River catchment including:

- *Waratah Coal Mine Project Styx River Catchment Aquatic Baseline Monitoring Program* (ALS Water Sciences Group, 2011): The 2011 post-wet season period baseline aquatic survey was completed in June 2011 following an above average rainfall period (as described in **Section 3.1.1** and shown in **Graph 3-2**). A total of nine (9) sampling sites were established (**Table 3-4**).
- *Preliminary Surface Water Resources Technical Report - Styx Coal Project, Styx Basin, Qld* (Yeats Consulting Engineers, 2012): A baseline water quality sampling program was established by Yeats Consulting Engineers in 2011-12 to characterise the waterways in the region and was undertaken alongside the *Styx River Catchment Aquatic Baseline Monitoring Program* (ALS Water Sciences Group, 2011) discussed above. In total, eleven (11) baseline water quality sites were sampled (**Table 3-4**) between June 2011 and March 2012.
- Chapter 9 of the Central Qld Coal Project SEIS (CDM Smith, 2018h): An extended baseline water quality sampling campaign in 2017-2018 to add to the ALS Water Sciences Group (2011) and Yeats Consulting Engineers (2012) datasets, as well as analysis by Environmental Isotopes (contracted by ALS) in 2018; and

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[16] Based on the approximate sub-catchment areas reporting direct to FHA-047 downstream of the North Coast Railway crossing.

Table 3-4

Surface Water Quality and Stream Health Sampling Campaign Summary

[ALS Water Sciences Group, 2011; Yeats Consulting Engineers, 2012; CDM Smith, 2017-18; CQCPL, 2019-20]

River/ Creek	Site Reference					Easting	Northing	Indicative Surface Water Quality [20th-80th%ile]		
	ALS WSG [2011]	Yeats [2011-12]	CDM Smith [2017-18]	CQCPL [2019]	General Description			pH	Electrical Conductivity [µS/cm]	Turbidity [NTU]
Styx River	St2	St2	St2	St2	Downstream sampling point located at the Ogmore Road bridge crossing at Ogmore, upstream of the Broad Sound Fish Habitat Area (FHA-047).	772243	7496104	7.3-8.0	1,783-**38,080**	8.8-124
	St1(b)[1]	-	-	-	Furthest upstream sampling point on the named Styx River.	772585	7495763	7.6	1,366	5.8
Granite Creek	Gr1	-	-	-	Reference sampling point at the Bruce Highway crossing in the sub-catchment of the Styx River.	761596	7497536	6.6-8.2	200-488	2.4-52.1
Montrose Creek	-	Mo1	-	-	Reference sampling point at the Bruce Highway bridge in the sub-catchment of the Styx River.	762904	7493706	6.8-7.9	169-730	2-59.1
	-	Mo2	-	-	Reference sampling point at the Montrose Creek Weir (used for non-potable water supply in Ogmore).	767734	7496264	7.3-8.3	171-719	4.5-84.3
Tooloombah Creek	To1	To1	To1 (1.1 & 1.2)	To1	Upstream sampling point located at the Bruce Highway bridge crossing. To1.1 and To1.2 were sampled nearby and analysed by Environmental Isotopes in 2018.	770191	7488488	7.4-8.2	288-870	5.3-58.2
	To2	To2	To2 (2.1 & 2.2)	To2	Sampling point located to the north-west of ML 80187, upstream of the confluence with Deep Creek. To2.1 and To2.2 were sampled nearby and analysed by Environmental Isotopes in 2018.	772639	7489376	7.7-8.4	359-1,409	3-64.2
	-	-	To3 (3.1 & 3.2)	To3	Downstream sampling point at northern extent of ML 80187, upstream of the confluence with Deep Creek. To3.1 and To3.2 were sampled nearby and analysed by Environmental Isotopes in 2018.	773488	7491085	7.6-8.3	578-1,498	4.8-50.3
	-	-	To3x	To3x	Additional downstream sampling point (near To3) at northern extent of ML 80187.	773229	7491014	7.7	1,902	4.4
	-	-	-	To4	Furthest upstream sampling point on Tooloombah Creek, upstream of Mamelon Creek confluence.	764228	7486329	7.0-7.8	281-405	81.3-554

Table 3-4 (Continued)
Surface Water Quality and Stream Health Sampling Campaign Summary
[ALS Water Sciences Group, 2011; Yeats Consulting Engineers, 2012; CDM Smith, 2017-18; CQCPL, 2019-20]

River/ Creek	Site Reference					Easting	Northing	Indicative Surface Water Quality [20th-80th%ile]		
	ALS WSG [2011]	Yeats [2011-12]	CDM Smith [2017-18]	CQCPL [2019]	General Description			pH	Electrical Conductivity [µS/cm]	Turbidity [NTU]
Tooloombah Creek [*Cont.*]	-	-	-	TC	Additional sampling point (near To2) during AMEC (2019) investigation.	772174	7489156	-	315-1,372~	-
	St1^	St1^	St1^	St1^	Previously named Styx River 1 (however is located within the named Tooloombah Creek watercourse – downstream sampling point located immediately downstream of the confluence of Deep Creek (reference site near a long-term Fitzroy Basin Association (FBA) monitoring point[17]).	773641	7493885	6.9-7.9	200 - 10,640	7.8-334.4
	[*FBA Community Datasets at St1 for Comparison – Only Wet Season Months*]							6.7-7.4	Specific Conductance Only	127-712
Deep Creek	De1#	De1	De1	De1	Upstream sampling point of proposed CQC Project toward south-east extent of ML 80187.	773447	7483818	7.3-8.2	309-814	7.6-103.7
	De2 [Riffle]	De2	De2	De2	Sampling point located at the Bruce Highway bridge crossing.	774869	7485802	7.2-8.2	182-642	9.5-880
	De3	De3	De3	De3	Sampling point at confluence with Barrack Creek.	774748	7491526	7.2-8.2	210-678	18.6-778
	-	-	De4	De4	Downstream sampling point at gauging station DeGS1.	774444	7490214	7.0-7.8	158-391	57.3-588.6
	-	-	De5	De5	Furthest downstream sampling point at northern extent of ML 80187.	774604	7491131	7.2-8.0	158-269	255-880
	-	-	-	DC1	Additional sampling point (near De2) during AMEC (2019) investigation.	774721	7485632	-	209-524~	-
	-	-	-	DC2	Additional sampling point (near De3) during AMEC (2019) investigation.	775987	7486672	-	210-337~	-

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[17] Protection and Restoration of Grazed, Natural Wetland Systems in the Fitzroy Basin (FBA, 1 July 2016 – 30 June 2017).

Table 3-4 (Continued)

Surface Water Quality and Stream Health Sampling Campaign Summary

[ALS Water Sciences Group, 2011; Yeats Consulting Engineers, 2012; CDM Smith, 2017-18; CQCPL, 2019-20]

River/ Creek	Site Reference					Easting	Northing	Indicative Surface Water Quality [20th-80th%ile]		
	ALS WSG [2011]	Yeats [2011-12]	CDM Smith [2017-18]	CQCPL [2019]	General Description			pH	Electrical Conductivity [µS/cm]	Turbidity [NTU]
Mamelon Station Farm Dams [Deep Creek Tributary]	-	-	-	Surveyors Waterhole	Sampling point upstream of Bruce Highway.	772762	7486362	6.5-7.7	157-425	61.5-408.8
	-	-	-	BPEast	Sampling point at old borrow pit water storage.	773226	7486545	7.5	649	429.0
	-	-	-	Ring Tank*	Turkeys nest dam adjacent to surveyed bores on Mamelon property (WP002 and Mm1).	773486	7486739	7.6	327	590.2
Barrack Creek[2]	-	Ba1	Ba1x	Ba1x	Sampling point(s) either just before confluence with Deep Creek (not sampled due to no flow in areas) or upstream at ML 700022 extent.	776564	7486324	7.6	1,293	6.0
[Rail Loop Tributary]	-	-	Ba1	Ba1	Sampling point upstream and east of ML 700022 extent.	776210	7486697	7.4	1,288	6.4
Amity Creek[+]	-	Am1[+]	-	Am1	Located in the Waverley Creek catchment.	759831	7506554	7.0-7.8	184-334	6.3-77.7

Source: Orange Environmental Pty Ltd (2020) [SEIS Appendix A5]

[1] One record.

[2] Two records (predominantly dry), median presented.

^ As described in **Section 3.2.1**, Site St1 is located within the mapped watercourse reach immediately downstream of the Deep Creek confluence, and for the purposes of this assessment (and consistency with current Qld Government nomenclature) is considered to be the lowest named reach of Tooloombah Creek. CDM Smith (2018h) report that it is this lowest reach which is potentially tidally influenced during peak tides.

[#] The sampling point (Easting 774280; Northing 7497536) during the baseline aquatic survey was located upstream of Bruce Highway crossing on Deep Creek, however not as far upstream as subsequent De1 sampling locations.

[+] Amity Creek is located in the Waverley Creek catchment, beyond the Styx River catchment, and was included for comparative purposes only. Noted as similar to Granite Creek and Montrose Creek.

[~] Minimum and maximum values during 2019 investigation.

* Laboratory results not available at time of reporting.

- CQCPL (2019-20): Continued baseline water quality sampling in 2019-20 with the future objective to establish site-specific triggers.[vii]

Prior to these campaigns, it is recognised that in 2006-2007 a preliminary assessment of the landscape condition in the Broadsound Basin was conducted by Melzer, *et al*. (2008) which relevantly concluded that many of the creeks of the region record high turbidity during periods of high flow due to the erodible and dispersive soils present in the catchment (Melzer *et al*., 2008).

From 2008 to 2012, the Fitzroy Basin Association (FBA) also conducted water quality sampling on Tooloombah Creek (at St1), upstream of the named Styx River reach, during wet season months and the available datasets have been included (**Table 3-4**). The total suite of water quality parameters included: pH, Specific Conductance, TSS, Turbidity, TP and TN.

As described in **Section 3.2.2**, Livingstone Shire Council manage a surface water extraction point on Montrose Creek as part of the Ogmore Water Supply System.

Opportunistic surface water quality sampling has also occurred at select farm dams / storages across the Mamelon property (i.e. Surveyors Hole [*Surveyors*], Ring Tank and Old Borrow Pit East [*BPEast*] of Bruce Highway) and is discussed in **Section 3.4.2**. When combined, more than 20 surface water quality sampling points have been monitored in several targeted baseline data collection campaigns by CQCPL (and others) within the Styx River catchment (**Figure 3-7**).

3.3 TIDAL INFLUENCE, STREAM FLOW, POOLS AND FLOODING

Long term mean sea level records are published by the Queensland Government in the Queensland Tide Tables Standard Port Tide Time 2019 (Maritime Safety Queensland, 2019) at locations along the Queensland eastern coastline to the north and south of the Broad Sound respectively:

- 3.420 m - Hay Point (near Mackay) [January 1985 to December 2016]; and
- 2.472 m - Rosslyn Bay (near Rockhampton) [January 1993 to December 2016].

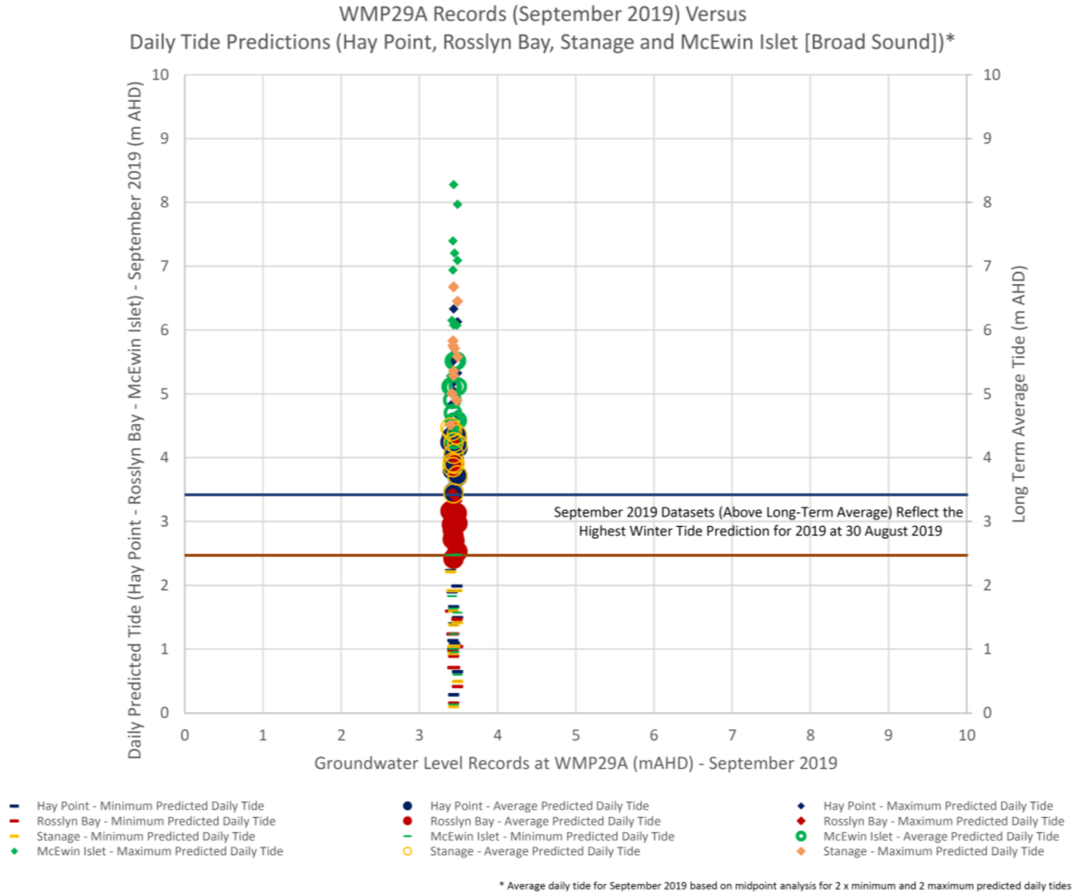
Mean sea level is equivalent to the Australian Height Datum as provided in Guide to Tidal Planes included in Maritime Safety Queensland (2019) (**Figure 3-8**).

Site-specific groundwater level data was recorded at WMP29A for comparison with predicted daily average tides at Hay Point, Rosslyn Bay, Stanage and McEwin Islet and is presented in **Graph 3-4**. It is noted that the commencement of the detailed water level record taking coincided with the highest winter tide predicted for 2019 at Hay Point and Rosslyn Bay (i.e. 5.0 mAHD and 6.93 mAHD) respectively, thus the September 2019 datasets are above the long-term averages.

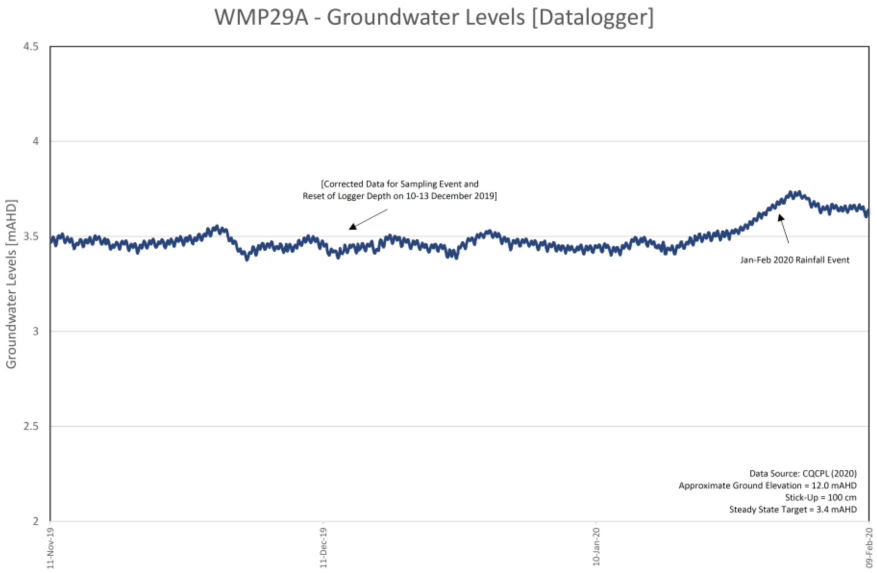
At a finer scale, hourly datalogging has occurred at WMP29A to investigate the influence of tides on groundwater levels. As shown in **Graph 3-5**, twice daily perturbations consistent with high and low tides are evident with an amplitude of generally less than 5 cm to 10 cm. Additional logger datasets are also presented in **Attachment 8**. Detailed survey measurement at WMP29A was also subsequently recorded for relative comparison and is presented in **Section 8.12.3**.

A Natural Disaster Resilience Program Storm Tide Hazard Interpolation Study Report (the NDRP Report) was prepared by GHD Pty Ltd on behalf of the Qld Government Department of Science, Information Technology, Innovation and the Arts in June 2014 (GHD Pty Ltd, 2014).

The NDRP Report drew upon the findings of the Storm Tide Risk Management Study for Broadsound Shire Council and Sarina Shire Council in 2003 (WS Group, CW and LT, 2003). The theoretical maximum storm tide levels presented in the NDRP Report suggests water elevations in the Broad Sound of >14 mAHD.



Graph 3-4
WMP29A Records (September 2019) Versus Daily Tide Predictions (Hay Point, Rosslyn Bay, Stanage and McEwin Islet [Broad Sound]



Graph 3-5
WMP29A Datalogger – Data Recorded Since Installation
[*Source: CQCPL, 2020*]

Consistent with the NDRP Report, the high and medium hazard mapping areas for storm tide in the Styx River catchment presented on Qld Globe suggests inland flooding could potentially extend as far as the Deep Creek confluence with Tooloombah Creek, downstream of the Project (**Figure 3-9**).

3.3.1 Broad Sound

The Broad Sound estuary is located (at its nearest point) approximately 4 km downstream of the Ogmore Road Bridge crossing, and for the purposes of this assessment is coincident with the defined boundary of the Broad Sound Fish Habitat Area (FHA-047) at the mouth of the Styx River (**Section 3.5.1**). Long term Styx River Mouth (i.e. Broad Sound) Tidal Monitoring datasets, statistics and predictions are available at a number of tidal monitoring points in the vicinity of the Broad Sound including:

- McEwin Islet (BOM);
- Stanage and Thirsty Sound; and
- Clairview, McEwen Island and Flock Pigeon Island.

3.3.2 Styx River

In 2011-12, waterway condition observations were recorded in the Styx River during the baseline water quality program by Yeats Consulting Engineers (2012). Specific reference was made to the Hay Point (Mackay) and McEwin Islet (i.e. 24 minutes after the Hay Point tidal prediction) for each recording, including:

- Low tide (-60; 0; +30; and +180 minutes);
- Mid tide; and
- High tide (-60; +45; and +120 minutes).

Relevantly, it is noted that during all observations, no flow observations recorded at Site St1 on Tooloombah Creek, downstream of the CQC Project at the confluence of Deep Creek, were identified as incoming) (i.e. only outgoing or nil).

In the 4th quarter of 2019, measurements of tide levels in the Styx River at the Ogmore Road bridge (to allow approximate correlation with McEwin Islet tidal predictions) were commenced. Each measurement was taken relative to the bottom of the Ogmore Road bridge deck, which was based on the Permanent Survey Marker (PSM) position and available survey dataset at the time with recordings to the end of 2019 presented in **Table 3-5**. Further details are provided in **Section 10.1.3**. Detailed survey measurement at the PSM was recorded for relative comparison and is discussed in **Section 8.12.3**.

CDM Smith (2018h) report that the tidally influenced portion of the Styx River is located up to approximately the Ogmore Road Bridge crossing with a transitional zone extending during peak tides (i.e. tidal bore) to the lowest reach of Tooloombah Creek, downstream of the Deep Creek confluence. This location is also comparable and generally consistent with the highest astronomical tide mapping based on Qld_LiDAR 5 m DEM source on Qld Globe (**Figure 3-9**).

Corresponding tidal influence recorded in an alluvial groundwater monitoring bore (WMP29A) is presented separately in **Graphs 3-4 and 3-5**.

Table 3-5
Tidal Water Monitoring – Styx River at Ogmore Road Bridge [CQCPL, 2019]

Date		BOM Tide Predictions[viii] at McEwin Islet	Measurement Time at Ogmore Road Bridge	Approximate Surface Water Level			
				Depth From PSM*		Absolute (mAHD)^	
				High Mark (Observed on Bank)	Water Level (at time)	High Mark (Observed on Bank)	Water Level (at time)
Oct	29	Low: 0.39 mAHD (6.10 am) High: 8.50 mAHD (12.08 pm)	-	-	-	-	-
	30	Low: 0.76 mAHD (6.50 am) High: 8.20 mAHD (12.48 pm)	12.00pm	2.10 m	3.49 m	5.15 mAHD	3.76 mAHD
	31	Low: 1.22 mAHD (7.26 am) High: 7.75 mAHD (1.25 pm)	9.00 am	2.91 m	3.48 m	4.34 mAHD	3.77 mAHD
Nov	1	Low: 1.70 mAHD (7.57 am) High: 7.20 mAHD (2.01 pm)	9.00 am	3.47 m	3.47 m	3.78 mAHD	3.78 mAHD
	25	Low: 0.44 mAHD (4.10 am) High: 8.50 mAHD (10.17 am)	12.45 pm	2.46 m	-	4.79 mAHD	-
	26	Low: 0.53 mAHD (5.01 am) High: 8.63 mAHD (11.05 am)	10.05 am	-	3.53 m	-	3.72 mAHD
	27	Low: 0.76 mAHD (5.47 am) High: 8.51 mAHD (11.48 am)	10.00 am	2.08 m	3.61 m	5.17 mAHD	3.64 mAHD
	28	Low: 1.08 mAHD (6.29 am) High: 8.20 mAHD (12.28 pm)	9.45 am	2.19 m	3.57 m	5.06 mAHD	3.68 mAHD

* Source: CQCPL (2019).
^Based on the surveyed elevation of 7.248 mAHD at the Permanent Survey Marker (PSM). Refer to **Section 8.12.3** for further details regarding survey investigations at the PSM.

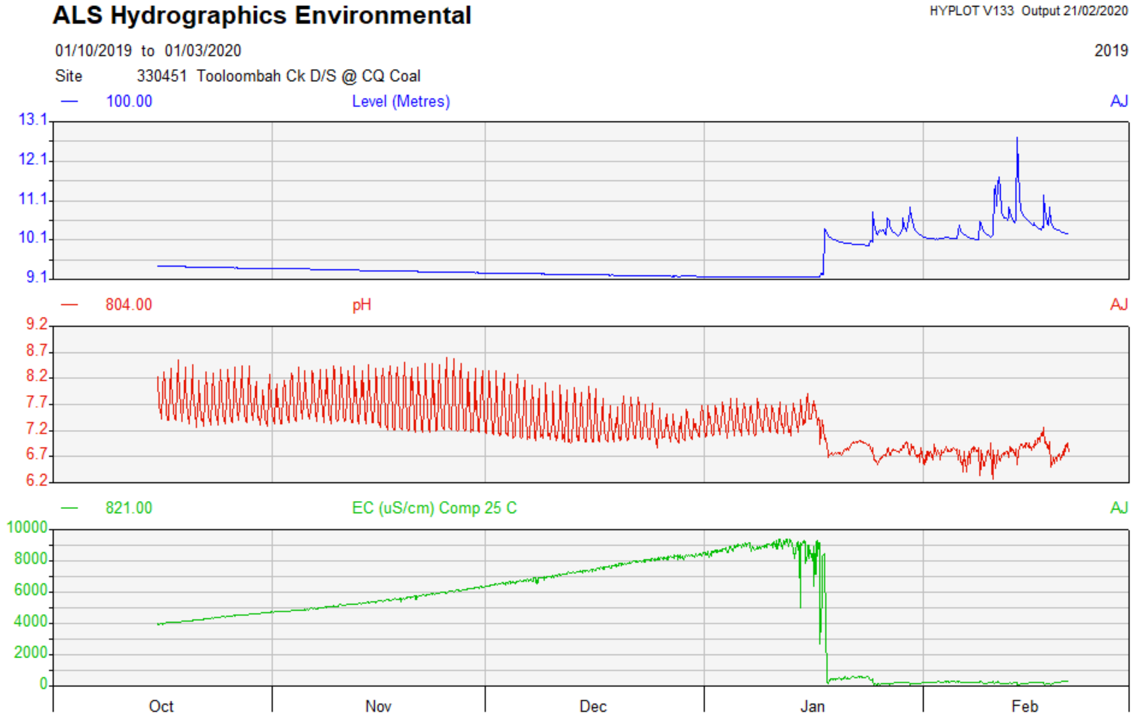
3.3.3 Tooloombah Creek

Surface water pool level, stream flow and water quality (including pH, EC, temperature) is continuously logged at the ALS Gauging Station (No. 330451) installed on Tooloombah Creek in October 2019. Telemetry allows for instantaneous access to flow and water quality data via the ALS Environmental web portal. The first recorded flow event since installation of Gauging Station No. 330451 on Tooloombah Creek occurred in January 2020 however the continued decline in pool water levels and corresponding EC increase was evident in the preceding months (**Graph 3-6**). Further details of the gauging station installation and continued baseline monitoring of stream flows and pool levels are provided in **Section 10.1.4**.

Notably, the pH fluctuations reflect the daily temperature oscillations and, unlike WMP29A, there is no discernible evidence of any tidal influence (i.e. twice daily oscillation) based on salinity measurements.

Continuous datalogging of groundwater levels in the nearby Quaternary (Pleistocene) Alluvium bore (WMP04) and future comparisons to the pool/stage levels in Tooloombah Creek are discussed in **Sections 5.4.2 and 7.8.1**.

Photographic plates of pools on Tooloombah Creek in February 2017 are also shown in **Plates 3-5 to 3-7**.



Graph 3-6
Gauging Station No. 330451 on Tooloombah Creek – Level/pH/EC Data Recorded Since Installation
[*Source: ALS Environmental, 21 February 2020*]

Plate 3-5
Tooloombah Creek Pool [February 2017] / Downstream of Bruce Highway Bridge
[*Source: Plate 9-3 in CDM Smith, 2018h*]

Plate 3-6

Tooloombah Creek Pools [February 2017] / Upstream of Bruce Highway Bridge

[Source: Plate 9-4 in CDM Smith, 2018h]

Plate 3-7

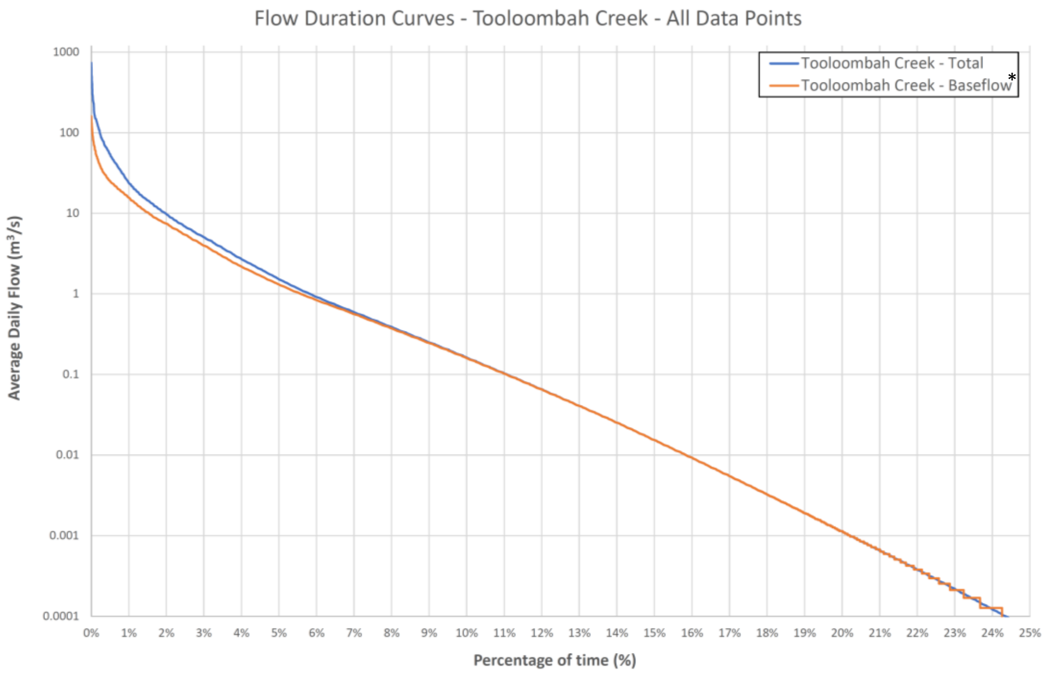
Tooloombah Creek Pool [February 2017] / Downstream Confluence with Deep Creek

[Source: Plate 9-5 in CDM Smith, 2018h]

It is also noted that CDM Smith (2018f) report that the occurrence of Marine Couch can be an indicator of a tidally influenced zone and has been observed to an in-stream elevation of approximately 6.5 mAHD, downstream of and below the confluence of Deep Creek and Tooloombah Creek. This downstream reach is also consistent with the highest astronomical tide mapping extent.

Tooloombah Creek Flow Duration Curve (WRM Water & Environment, 2020)

WRM Water & Environment (2020) has developed a flow duration curve for Tooloombah Creek based on an Australian Water Balance Model (AWBM) for the catchment and the curve is presented in **Graph 3-7**. For details in relation to the AWBM baseflow index and AWBM baseflow recession constant (Kb) refer to WRM Water & Environment (2020). WRM Water & Environment (2020) estimate that Tooloombah Creek has little (<0.1 ML/day) to no flow for more than 80% of the time, with AWBM baseflow (or interflow) contributing to the total flow for a large proportion of the flow period. Further discussion of this concept (i.e. extended interflow) is provided in **Section 6.3.3**.



Graph 3-7
Tooloombah Creek Flow Duration Curve
[***Source: WRM Water & Environment, Email 28 May 2020***] *(with annotation)*
* AWBM Derived Baseflow (or Interflow)

Tooloombah Creek Flood Elevation (WRM Water & Environment, 2020)

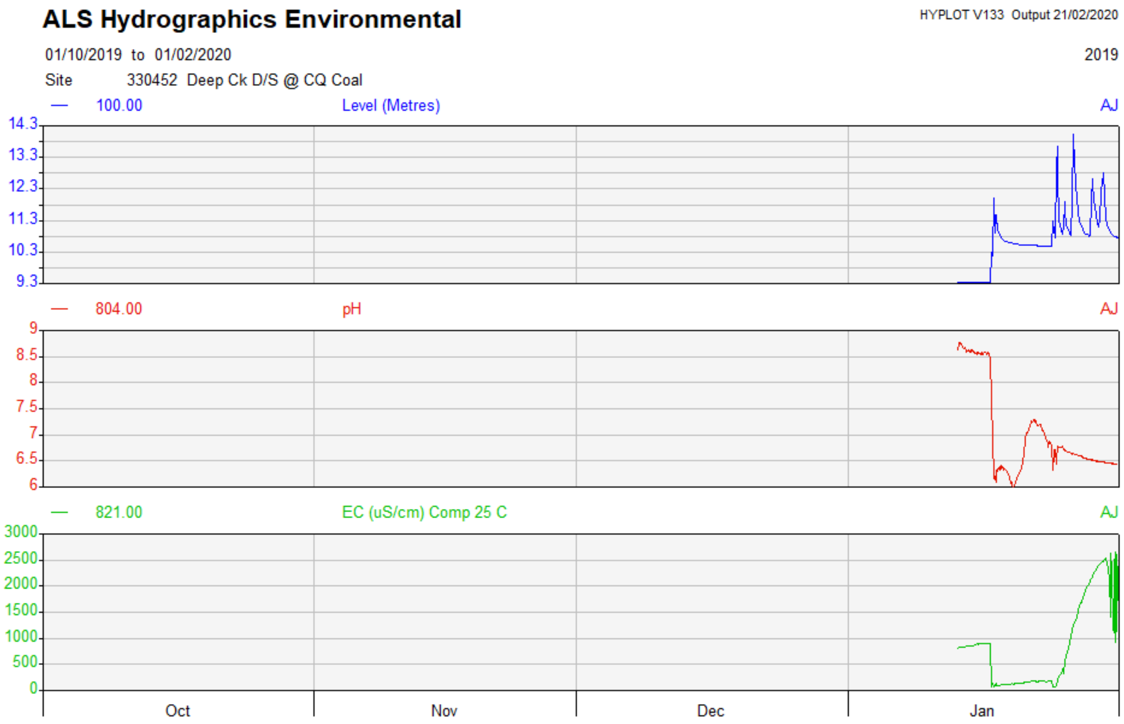
WRM Water & Environment (2020) has also modelled and generated peak flood depth, elevation and velocity grids for 10% annual exceedance probability (AEP) design event (for existing conditions) along Tooloombah Creek in the vicinity of the CQC Project.

A comparison of the model generated flood elevation cross-section perpendicular to the location of WMP06 shows that surface water levels in Tooloombah Creek could be in the order of approximately 25 mAHD and above.

3.3.4 Deep Creek

As discussed in **Sections 3.2.4 and 3.2.7**, surface water sampling (for water quality analysis), water hole and pool observations have been recorded at Deep Creek for an extended period. Surface water pool level, stream flow and water quality (including pH, EC, temperature) is continuously logged at the ALS Gauging Station (No. 330452) installed on Deep Creek in October 2019. Telemetry allows for instantaneous access to flow and water quality data via the ALS Environmental web portal.

The first recorded flow event since installation of Gauging Station No. 330452 on Deep Creek occurred in January 2020 (**Graph 3-8**). Further details of the gauging station installation and continued baseline monitoring is provided in **Section 10.1.5**.



Graph 3-8
Gauging Station No. 330452 on Deep Creek – Level/pH/EC Data Recorded Since Installation
[***Source: ALS Environmental, 1 February 2020***]

Continuous datalogging of groundwater levels in the nearby Quaternary Alluvium bore (WMP05) and comparisons to the pool/stage levels in Deep Creek are also provided in **Section 5.4.2**. Photographic plates of pools and dry reaches on Deep Creek (in February 2017) are shown in **Plates 3-8 and 3-13**.

As part of the AMEC (2019) groundwater investigation (**Attachment 7**), waterhole and pool level measurements were recorded on a regular basis (generally every 2nd day) (**Plate 3-12**). In contrast to the baseline water quality monitoring and observations undertaken by ALS Water Sciences Group (2011) and Yeats Consulting Engineers (2012) which coincided with the period following the 2010-11 Qld floods, and the subsequent monitoring and observations reported by CDM Smith (2018e) following Cyclone Debbie in 2017, the 2019 baseline monitoring period has coincided with an extended below average rainfall period (**Section 3.1.1**; **Graph 3-2**). As evidenced by the surface water datasets recorded by AMEC in 2019, the waterhole / pools monitored at Deep Creek 1 and Deep Creek 2 had been dry for the 2nd half of 2019. A subsequent inspection by CQCPL personnel in October 2019 confirmed the prevailing dry observations (**Plates 3-9 to 3-12**).

Plate 3-8
Deep Creek Pool [February 2017] / Downstream of Bruce Highway Bridge
[Source: Plate 9-1 in CDM Smith, 2018h]

Plate 3-10
Deep Creek Pool [October 2019] / Downstream of Bruce Highway Bridge

Plate 3-9
Deep Creek Dry Reach [February 2017] / Upstream of Bruce Highway Bridge
[Source: Plate 9-2 in CDM Smith, 2018h]

Plate 3-11
Deep Creek Dry Reach [October 2019] / Upstream of Bruce Highway Bridge

Plate 3-12
Deep Creek 1 Dry Sampling Point
[17 October 2019]

Plate 3-13
Deep Creek Near WMP10 [26 September 2017]
[Source: Mitchell Services, 2017

Relevantly, evidence of flooding following the 2010-2011 flood event was noted during the ALS Water Sciences Group (2011) Baseline Aquatic Survey in June 2011 with debris in trees found 7-8 m above the measured water level at that time.

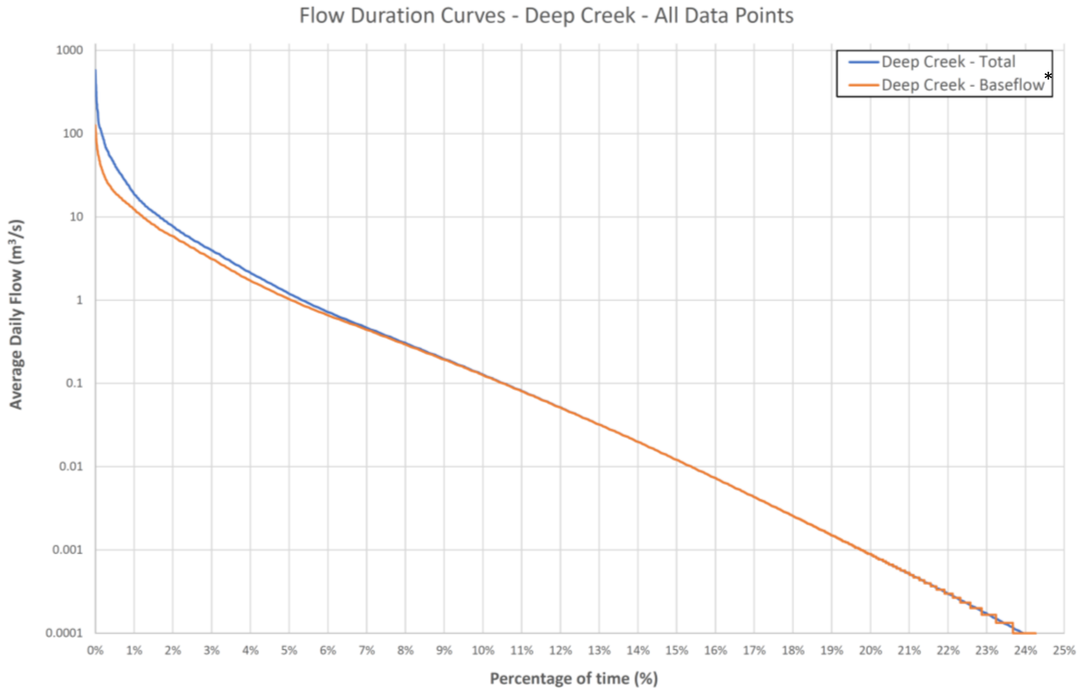
Deep Creek Flow Duration Curve (WRM Water & Environment, 2020)

WRM Water & Environment (2020) has developed a flow duration curve for Deep Creek based on an Australian Water Balance Model (AWBM) for the catchment and the curve is presented in **Graph 3-9**. For details in relation to the AWBM baseflow index and AWBM baseflow recession constant (Kb) refer to WRM Water & Environment (2020).

Similar to Tooloombah Creek, WRM Water & Environment (2020) estimate that Deep Creek also has little (<0.1 ML/day) to no flow for more than 80% of the time, with AWBM baseflow (or interflow) contributing to the total flow for a large proportion of the flow period. Further discussion of this concept (i.e. extended interflow) is provided in **Section 6.3.3**.

3.3.5 Other Drainage Features

There are a number of other drainage features (**Plates 3-14 and 3-15**) which drain the existing properties to the local creek lines, with the most prominent being the unnamed features extending generally in a south-west to north-east direction from the Mamelon Station Homestead, through the central areas of the CQC Project areas, traversing beneath the Bruce Highway and eventually reporting to Deep Creek toward the north-east. A number of farm dams exist along the drainage features and near the culverts extending beneath the Bruce Highway and are discussed separately in **Section 3.4.2**.



Graph 3-9
Deep Creek Flow Duration Curve
[Source: WRM Water & Environment, Email 28 May 2020] *(with annotation)*
* AWBM Derived Baseflow (or Interflow)

Plates 3-14 and 3-15
Dry Tributary [WB6] of Unnamed Drainage Feature on Mamelon Station [September 2018]
Dry Unnamed Drainage Feature [WB8d] on Mamelon Station [August 2018]
[Source: Waterway Barrier Works Assessment, CQCPL & FCPL (2018)]

3.4 ANTHROPOGENIC LAND USE

In 2008, Melzer *et al*. reported that the main land use in the region was agriculture which occupied 78% of the catchment (in the '*Broadsound Basin*'), and cattle grazing the predominant form of agriculture carried out.

Many cleared areas were described as badly eroded from sheet and gully erosion, particularly in the centre of the catchment and occurred in association with particular soil types. In 2006-07 declining ground cover had resulted in 30.3% of the catchment being classified as being in a highly or very highly disturbed condition (Melzer *et al*., 2008).

In 2013 an audit of agricultural land in Qld was completed by the Department of Agriculture, Fisheries and Forestry (DAFF) (2013) and relevantly covered the 'Central Queensland' Agricultural Land Audit region (**Figure 3-10**) within which the CQC Project is located. Since then, Annual Addenda (DAFF, 2014; DAF, 2017) have been published which outline and highlight relevant land use information and data. In the past two decades, a number of regional land use related plans and statements have been prepared, revised and expanded, notably:

- *Central Queensland Regional Plan* (DSDIP, 2013) (**Figure 3-11**);
- *Reef Water Quality Protection Plan 2003* (State of Queensland and Commonwealth of Australia, 2003);
- *Reef Water Quality Protection Plan 2009* (Reef Water Quality Protection Plan Secretariat, September 2009);
- *Reef Water Quality Protection Plan 2013* (Reef Water Quality Protection Plan Secretariat, July 2013a);
- *2013 Scientific Consensus Statement - Land Use Impacts on Great Barrier Reef Water Quality and Ecosystem Condition* (Reef Water Quality Protection Plan Secretariat, July 2013b); and
- *2017 Scientific Consensus Statement - Land Use Impacts on Great Barrier Reef Water Quality and Ecosystem Condition* (Waterhouse *et al*., 2017).

Locally, the CQC Project is predominately situated within the Mamelon property, which runs cattle and produces dryland crops (CDM Smith, 2018e). The Mamelon property is owned by the proponent and is currently leased for cattle grazing (**Section 3.4.1**). Supporting this land use is a series of farm dams and surface contour bunds that capture and store runoff generated by the local contributing catchments (**Section 3.4.2**).

Ogmore (an historical coal mining and rail township) is the nearest populated centre (albeit small) to the CQC Project. Subordinate land uses in the broader Styx River catchment also include quarry reserves, nature conservation (e.g. Burwood Nature Refuge) and state forests (e.g. Marlborough and Mount Buffalo State Forests) and minimal use in the rugged hills associated with Broad Sound Range.

Groundwater bores are used by some landholders in the region to supply water to dams and/or storage tanks for the purposes of stock and domestic water supply (**Section 5.2.3**). There are also three (3) reported surface water entitlements in the Tooloombah Creek and Deep Creek sub-catchments for irrigation, stock and domestic supply and are discussed in **Section 3.4.1**.

3.4.1 Agricultural Activities and Existing Landholder Water Use Entitlements

The land within and surrounding the CQC Project area is predominately used for cattle grazing and some dryland cropping.

Reported surface water entitlements to support agricultural activities along Deep Creek and Tooloombah Creek for irrigation, stock and domestic water supply are as follows (CDM Smith, 2018e; Orange Environmental Pty Ltd, 2020):

- 20 ha authorised for irrigation (Property 119/CP900367) sourced from Deep Creek (approximately 3 km downstream of the CQC Project);
- 8 ha authorised for irrigation (Property 45/MPH26062) sourced at an existing extraction point to supply a small off-stream storage on the western overbank of Tooloombah Creek (neighbouring property north-west of the CQC Project); and
- 18 ML per annum for stock and domestic supply (Properties 1/RP616700 and 19/MC495) sourced from Tooloombah Creek (neighbouring property north of the CQC Project).

It is however noted that as a Water Plan has not been established for the Styx Surface Water Basin (**Section 2.1.2**), landholders do not need a water licence under the *Water Act 2000* for stock and domestic supply.

Albeit beyond the Styx River catchment, sugar cane farming is known to occur in the Clairview Creek catchment (e.g. Racecourse Projects) within the broader Styx Surface Water Basin.

3.4.2 Farm Dams and Contour Bunds

A number of farm dams exist along the drainage features and near the culverts extending beneath the Bruce Highway on the Mamelon property. The 'Surveyors Waterhole' mapped on the Australian Groundwater Explorer[ix] database is one of the central farm dam water storages used on the Mamelon property. Several other farm dams exist across the Mamelon property as shown on **Plates 3-16 and 3-17**. Opportunistic surface water quality sampling has occurred at select farm dams (Surveyors Waterhole, BPEast, and Ring Tank; **Figure 3-7**) across the Mamelon property with the results presented in **Table 3-4**.

Plate 3-16
Farm Dam [Ref. 696686] on Mamelon Property (South of Bruce Highway)
[Source: Plate 9-7 in CDM Smith, 2018h]

Plate 3-17
Farm Dam [Rural Water Storage] on Mamelon Property (South of Bruce Highway)
[Source: Plate 9-8 in CDM Smith, 2018h]

The Waterway Barrier Works Assessment (CQCPL & FCPL, 2018) identified that a number of the drainage features on the Mamelon property had historically been subject to substantial modification with a number of farm dams and berms/flooded pasture areas constructed across previously mapped waterways. The existing catchment contour bunds on the Mamelon property to the south of the Bruce Highway also provides for erosion protection.

3.4.3 Bruce Highway Crossings and Drainage Infrastructure

Further to the description in **Section 3.4.2**, a number of verge drains and culverts exist where the Bruce Highway bisects the Mamelon property in the vicinity of the CQC Project, in addition to the bridge crossings of Deep Creek and Tooloombah Creek.

3.4.4 Non-Potable Town Water Supply

As described in **Section 3.2.2**, non-potable water is pumped directly from the Montrose Creek Weir (a small, 0.5 m high concrete weir, with a storage capacity of approximately 12 megalitres) to four small ground level storage tanks in the Ogmore township and is distributed periodically to residents.

3.4.5 Exploration and Coal Mining

An overview of exploration history and coal mining in the Styx River Coalfield is provided below. Current exploration and mining tenements are also described.

Exploration History

Styx River Coalfield

Coal was first discovered in the Styx River area in 1887, and prospecting followed initially for the next 2-3 years. One of the earliest Styx River Coalfield maps was prepared by the Geological Survey of Queensland (W.H. Rands, 1892) (**Figure 3-12**). Further details of initial prospecting (including shaft development) in advance of coal mining operations at the Styx No.1, Styx No.2, Styx No.3 State Coal Mines and the Bowman Coal Mine is described further below.

CQC Project Tenements and Surrounds

Historical exploration data from the Geological Survey of Queensland (27 drill holes), Earth Resources Australia Pty Ltd in 1981 (seven drill holes) and New Hope Collieries in 1994 (**Table A4-2**) (nine drill holes) are available for the CQC Project area and surrounds.

An extensive exploration drilling program was conducted within EPC 1029 between 2010 and 2014 with a total of 137 holes drilled including 68 chip holes and 69 fully cored HQ sized holes.

Data from these prior drill programs have been included in geological modelling to aid the understanding of the deposit and plan further exploration drilling for the CQC Project. The Geological Model was last updated in 2018 by CQCPL and forms the basis for the numerical groundwater model layers as described in **Sections 4.2.2 and 7.4.1**.

Mining History

The CQC Project is located in the Styx River catchment which has a long history of coal mining. Development of the Styx River Coalfield (**Figures 3-12** and **3-13**) began in 1918 at the Styx No.1 State Coal Mine at Bowman, followed shortly thereafter to the south by the Styx No.2 State Coal Mine.

In 1924, the Styx No.3 State Coal Mine (**Figure 3-14**) began production at Hartley (later named Ogmore). From 1930 to 1948, the Bowman Coal Mining Syndicate extracted coal at the underground mines in Bowman (**Figures 3-13 and 3-14**). The Styx No.3 State Coal Mine in Ogmore was closed in 1964 (Carpenter, 1991 in CDM Smith, 2018i).

The CQC Project is predominantly located within the Deep Creek sub-catchment of the Styx River catchment, upstream of the historic coal mines at Bowman and Ogmore. Other small historic mining/ quarry operations were also known to have existed in the Styx River catchment near the confluence of Tooloombah Creek and Mamelon Creek (Carpenter, 1991 in CDM Smith, 2018i).

Styx No.1 and No. 2 State Coal Mine

Old plans of the Styx No.1 and Styx No.2 State Coal Mines, relative to the Bowman Coal Mine, are presented in the Geological Survey Report prepared by the District Geologist (S.R.L. Shepherd, 10 February 1949) in the Styx River Coalfield. However, it is duly noted that there was very little available geological data at that time about the south-eastern section nearest to the Bowman Coal Mine and therefore only the approximate limit of workings is shown (**Figure 3-13**). Development and mining of the Styx No.1 and No.2 State Coal Mines occurred between 1918 and 1925 with production totalling 4,930 tons and 103,344 tons respectively (Malone, 1965).

Styx No.3 State Coal Mine (Formerly Named Hartley Mine)

Old plans of the Styx No.3 State Coal Mine Area in the Styx River Coalfield at Ogmore are presented in the Geological Survey Reports prepared by the Geologist (E.S.C. Chong, June 1964) showing boreholes, mine workings and reserves (**Figure 3-15[a]**). As shown on the corresponding cross-section (**Figure 3-15[b]**), the historic mine workings extended beneath the Styx River at Ogmore.

Generalised bore sections showing the depths to the top working seam, bottom working seam and lower seam at the Styx No.3 State Coal Mine are shown on **Figure 3-16**. Based on a review of geological logs by CQCPL's geologists, it is understood that the top and bottom working seams that were historically mined at the Styx No.3 State Coal Mine at Ogmore generally correlate with the Red Seam and Blue Seam identified at the CQC Project area. Reported borehole depths are presented in **Table 3-6**.

Table 3-6
Styx No.3 State Coal Mine – Summary of Bore Hole Depth Details

Borehole [refer **Figure 3-16**]	Collar RL	Top Working Seam *[e.g. Red Seam]**	Bottom Working Seam *[e.g. Blue Seam]**	Lower Seam *[e.g. Purple Seam]**
N.S. 26	38.2 ft [or 11.6 m]	298 ft 3 in [or 90.9 m]	439 ft 3 in [or 133.9 m]	583 ft 1 in [or 177.7 m]
N.S. 25	35.0 ft [or 10.7 m]	262 ft 9 in [or 80.1 m]	397 ft 7 in [or 121.2m]	509 ft 4.5 in [or 155.3 m]
N.S. 24	40.6 ft [or 12.4 m]	294 ft 3.5 in [or 89.7 m]	450 ft 9 in [or 137.4 m]	547 ft 6 in [or 166.9 m]
N.S. 7	40.8 ft [or 12.4 m]	305 ft [or 93.0 m]	463 ft 4 in [or 141.2 m]	562 ft 2 in [or 171.4 m]
No. 7	-	388 ft 2 in [or 118.3 m]	572 ft 3 in [or 174.4 m]	622 ft [or 189.6 m]

Source: After Chong (1964).
* Equivalent correlations with the seam nomenclature at the CQC Project based on review of geological logs by CQCPL's geologists.

Development of the Styx No.3 State Coal Mine commenced in 1923. During initial development and operation the top working seam was targeted, before the bottom working seam was mined between 1925 and 1952. From 1952 until cessation in 1964, all coal produced was mined from the top working seam (Chong, 1964).

In total, 1,556,251 tons of coal was produced during the operational mine life of the Styx No.3 State Coal Mine (Malone, 1965); the most productive of the historic mines at Ogmore and Bowman.

Further discussion and consideration of the historic mine workings in the development of the numerical groundwater model layers is included in **Section 7.4.1**.

Bowman Coal Mine (Bowman Coal Mining Syndicate)

A Geological Survey Report was prepared by the District Geologist (S.R.L. Shepherd, 10 February 1949) for the Bowman Coal Mine in the Styx River Coalfield after the mine ceased operations in November 1948. It is noted that the Geological Survey Report was largely restricted to the deeper levels (No. 3, No.4 and No.5), and that information for the upper workings of the Bowman Coal Mine were based only on official reports obtained at the time.

A summary of relevant details from the Geological Survey Report for the purposes of the groundwater assessment, for cumulative assessment purposes, is provided in **Table 3-7** and corresponding composite plans and diagrammatic sections shown on **Figure 3-17**.

Table 3-7
Bowman Coal Mine – Summary of Details

<table>
<tr><th>Attribute</th><th colspan="2">Details</th></tr>
<tr><td>Name / Lease</td><td>Bowman Coal Mine</td><td>Coal Mining Lease: No.227 (320 acres or 1.3 km^2)</td></tr>
<tr><td>Mining Type/ Method</td><td>Underground Mine</td><td>Shafts, Tunnels and Drives</td></tr>
<tr><td>Prospecting</td><td>1930 and 1931</td><td>Shaft No.1 (74 ft or 22.5 m) and
Shaft No.1 Drive (131 ft or 40 m)
Shaft No.2 (96 ft or 29.3 m) and
Connecting Drive to Shaft No.1 Drive</td></tr>
<tr><td>Years in Operation</td><td>Commencement Date: 1932</td><td>Cessation Date: November 1948</td></tr>
<tr><td>Production Schedule</td><td colspan="2">
<table>
<tr><td>Year</td><td>1932</td><td>1933</td><td>1934</td><td>1935</td><td>1936</td><td>1937</td><td>1938</td><td>1939</td><td>1940</td></tr>
<tr><td>Tons</td><td>211</td><td>2,736</td><td>9,147</td><td>7,621</td><td>5,326</td><td>5,669</td><td>4,400</td><td>3,473</td><td>3,370</td></tr>
<tr><td>Year</td><td>1941</td><td>1942</td><td>1943</td><td>1944</td><td>1945</td><td>1946</td><td>1947</td><td>1948</td><td>All</td></tr>
<tr><td>Tons</td><td>4,059</td><td>3,966</td><td>3,221</td><td>2,756</td><td>3,126</td><td>2,459</td><td>2,014</td><td>1,373</td><td>64,927</td></tr>
</table>
</td></tr>
<tr><td rowspan="8">Number of Levels</td><td rowspan="8">Five Levels (and Main Tunnel)</td><td>No. 1 Level: 151 ft (or 46.0 m)</td></tr>
<tr><td>No.2 Level: 278 ft (or 84.7 m)</td></tr>
<tr><td>No.3 Level: 352 ft (or 107.3 m)</td></tr>
<tr><td>No.4 Level: 438 ft (or 133.5 m)</td></tr>
<tr><td>No.5 Level: 521 ft (or 158.8 m)</td></tr>
<tr><td>Main Tunnel Dip Surface to No.1: 22 degrees</td></tr>
<tr><td>Main Tunnel Dip No.1 to No.4: 27 degrees</td></tr>
<tr><td>Main Tunnel Dip No.4 to No.5: 30 degrees</td></tr>
<tr><td>Proved Reserves</td><td colspan="2">10,000 tons (Between No. 3 and No. 5 Levels)</td></tr>
</table>

Source: After Shepherd (1949).

Existing Tenements

In total, approximately two-thirds of the Styx River catchment is currently subject to existing tenements, including Exploration Permit for Coal (EPC), Exploration Permits for Minerals other than Coal, Mineral Development Licence (MDL) and Mining Lease Surface Application Areas.

Four (4) EPC tenements exist within the Styx River catchment, *viz*.:

- EPC 1029 (Fairway Coal Pty Ltd);
- EPC 2128 (Scorpion Energy Pty Ltd);
- EPC 2268 (Fairway Coal Pty Ltd); and
- EPC 2392 (Civil & Mining Resources Pty Ltd).

Six (6) EPM tenements existing within the Styx River catchment, *viz*.:

- EPM 19825 (Evolution Mining (Connors Arc) Pty Ltd);
- EPM 25763 (Evolution Mining (Connors Arc) Pty Ltd) [Mt Mackenzie East];
- EPM 26885 (Capricornia VTI Pty Ltd) [North Marlborough Gabbros];
- EPM 26848 (Super Cruser Pty Ltd) [Mountain Maid];
- EPM 27026 (Mineralogy Pty Ltd) [Marlborough North]; and
- EPM 27027 (Mineralogy Pty Ltd) [Marlborough Central];

One (1) MDL exists at the CQC Project area and surrounds (MDL 468) and the two (2) Mining Lease Surface Application Areas within the Styx River catchment relate to the CQC Project, *viz*.:

- ML 80187 (Central Queensland Coal Pty Ltd) [Styx Coal South]; and
- ML 700022 (Central Queensland Coal Pty Ltd) [Styx Coal East].

As discussed above, Coal Mining Lease No. 227 was previously associated with the historic mining at Bowman Coal Mine.

3.4.6 Coal Seam Gas and Other Exploration

Coal Seam Gas (CSG) Exploration

There are currently no exploration permits for petroleum (EPP) within the Styx River catchment. However, relatively recent (historic) EPP 700 was held by Arrow Energy and a number of CSG exploration boreholes drilled including several in the vicinity Styx River catchment (**Table 3-8**):

- 59296 (Styx River 1) [to 659.6 m total depth] (Arrow Energy N.L., 2005);
- 60493 (Styx River 2) [to 365.31 m total depth] (Arrow Energy N.L., 2007[a]); and
- 60494 (Styx River 3) [to 472.2 m total depth] (Arrow Energy N.L., 2007[b]).

Additional CSG exploration boreholes were also drilled further north within the Styx Surface Water Basin including Styx River 5, 6, 6A, and 8. Several other historic EPPs (e.g. 77, 93, 103, 162, 716) have also been held across the broader Styx River region and beyond.

Table 3-8
Arrow Energy Well Completion Reports in the Styx River Catchment (2005-2007)

ID	Arrow Energy Drill Hole	Easting	Northing	Surface Elevation (m AMSL)	Depth of Alluvium	Thickness of Styx Coal Measures	Depth to Top of Back Creek Group
59296	Styx River 1	774917	7500412	15.1 m	24.1 m	528.8 m	552.9 m
60493	Styx River 2	773610	7494174	14.2 m	18.6 m	296.0 m	314.6 m
60494	Styx River 3	772397	7497622	18.4 m	16.8 m	326.5 m	343.3 m

Source: Arrow Energy N.L. (2005; 2007a; 2007b).
AMSL = Australian Mean Sea Level

Geothermal Exploration

Based on a search of available Government database records, a Geothermal Heat Flow Bore (St Lawrence 1) stratigraphic hole appears to have been drilled to a depth of 340 m by the Geological Survey of Queensland at the confluence of Deep Creek and Tooloombah Creek in 2011 (ID 64150), however no further information was able to be sourced.

3.4.7 Likely Expansions to Shoalwater Bay Training Area (Department of Defence)

It is understood that the Australian Government Department of Defence has undertaken land acquisitions to the north-east of the CQC Project, beyond the North Coast Railway Line. The land acquisitions are within the mapped likely expansion area to the existing Shoalwater Bay Training Area[x].

The existing Shoalwater Bay Training Area has been one of Australia’s prime military training areas since 1965 and the main activities include or have included the use of weapons ranges and firing ranges (Commonwealth of Australia, 2017). The existing Shoalwater Bay Training Area is beyond the Styx River catchment and therefore beyond the numerical groundwater model domain (**Section 7.0**).

3.5 WETLANDS

As described in **Section 2.1.3**, whilst the *Environmental Protection (Water and Wetland Biodiversity) Policy 2019* is substantially similar to the superseded policy, a key change was the relocation of the ‘Map of referable wetlands’ from the *Environmental Protection Regulation 2008* and renaming as the ‘Map of Queensland wetland environmental values’. The updates have been considered herein.

3.5.1 Directory of Important Wetlands in Australia

The Broad Sound (QLD003) is listed in the Directory of Important Wetlands in Australia (DIWA)[xi], comprising an area of 211,765 ha.

As a conservation measure, parts of the Broad Sound and adjoining estuarine systems were gazetted as a Declared Fish Habitat Area (FHA-047) by the Qld Government Department of Primary Industries and Fisheries on 28 March 2008 and is discussed below.

Broad Sound Declared Fish Habitat Area (FHA-047)

The boundary of the Broad Sound Fish Habitat Area (FHA-047) is defined at the mouth of the Styx River by the cadastral boundary (at a point 20 m from and parallel to) the North Coast Railway Line crossing of the Styx River (immediately downstream of the Granite/Montrose Creek confluence with the Styx River).

The boundary of the Broad Sound Fish Habitat Area (FHA-047) is also generally coincidental with the General Use Zone defined by the *Marine Parks (Great Barrier Reef Coast) Zoning Plan 2004*[xii] and is illustrated on **Figure 3-5**. For the purposes of this groundwater assessment, the Broad Sound Fish Habitat Area (FHA-047) has been consistently defined and assessed accordingly.

3.5.2 Wetlands of High Ecological Significance (HES)

Wetland 1 (Ref 688938) is located on the western boundary of ML 80187 (south-west of Open Cut 1) and identified as a wetland of high ecological significance (HES) within the Great Barrier Reef (GBR) river catchments subject to the Map of Great Barrier Reef Wetland Protection Areas (**Figure 3-18**) which extends broadly from the Daintree to Fraser Island. Wetland protection areas under State Code 9 of the State Development Assessment Provisions are shown on the Map of Great Barrier Reef Wetland Protection Areas, as defined in the *Environmental Protection Regulation 2019*.

A photographic comparison of Wetland 1 before and after the rainfall event associated with Cyclone Debbie in 2017 is presented in **Plate 3-18**. Site-specific investigations have occurred at Wetland 1 with a summary of the drill hole information and standpipes installed provided in **Section 5.1.4**.

Plate 10-9 Wetland 1 prior to Cyclone Debbie (February 2017)

Plate 10-10 Wetland 1 after Cyclone Debbie (May 2017)

Plate 3-18
GBR HES WPA Wetland 1 / South-West of Open Cut 1 [Tooloombah Creek Catchment]
[*Source: Plates 10-9 & 10-10 in CDM Smith, 2018f*]

3.5.3 Other Wetlands of General Ecological Significance (GES)

Wetland 2 (Ref 688644) is located on the western boundary of ML 80187, to the north of the Wetland 1, and identified as a wetland of general ecological significance (GES).

Site-specific investigations have occurred at Wetland 2 with a summary of the drill hole information and standpipes installed provided in **Section 5.1.4**.

3.5.4 Artificial Wetlands or Other

A number of the existing farm dams / storages and lower-lying areas where ponding occurs as a result of contour bunds, have been mapped by the DES as artificial wetlands. These areas are described separately in **Section 3.4.2**. Surface water quality monitoring has also occurred at select dams as described in **Section 3.2.7**.

Separate investigations of other wetland regional ecosystems (referred as Wetlands 3, 4 and 5) are presented in WRM Water & Environment (2020) and not considered herein.

4.0 GEOLOGY, SOILS, GEOCHEMISTRY AND GEOMORPHOLOGY

The earliest geological investigations in the Styx River area were undertaken to assist in coal prospecting and mapped in detail at the time by T.W.E. David in about 1890 (Malone, 1965). In 1892, a map of the Styx River Coalfield was prepared by Geological Survey of Qld (Rands, 1892) (**Figure 3-9**).

Given the long history of coal exploration and mining in the Styx River Coalfield (**Section 3.4.5**), and more broadly the Bowen Basin in Qld, the geology of CQC Project area and surrounds has been mapped by a number of sources and different scales, including:

- **1:2,000,000 Scale** Queensland Geology (based on Geology compiled by I.W. Withnall, P.R. Blake, F.E. von Gnielinski, R.J. Bultitude, D.J. Purdy and L.J. Hutton using publicly available data held by the Geological Survey of Queensland and Geoscience Australia, including supporting Queensland Geology Framework (DNRM, 2012) (**Figures 4-1[a-b]**);
- **1:250,000 Scale** Geological Series Saint Lawrence Sheet SF/55-12 First Edition 1970 (based on Geology, 1964 by E.J. Malone, F. Olgers, A.R. Jensen, R.G. Mollan and C.M. Gregory [Bureau of Mineral Resources]; A.G. Kirkegaard and V.R. Forbes [Geological Survey of Queensland], compiled by E.J. Malone in 1965 including supporting Explanatory Notes (Malone, 1965) (**Figures 4-2[a-c]**); and
- **1:100,000 Scale** Geological Series Marlborough Sheet 8852 First Edition 2004 Revised March 2006 (DNRMW, 2006) (**Figures 4-3[a-e]**).

The Geological Survey of Qld also published a detailed compilation of geological information of twenty 1:100,000 map sheet areas (including the Marlborough Sheet 8852) in *Queensland Geology 12: Geology of the Auburn Arch, Southern Connors Arch and Adjacent Parts of the Bowen Basin and Yarrol Province, Central Queensland* (Withnall, *et al*. 2009).

The following sub-sections draw upon the past geological investigations and mapping as well as more localised and refined geological investigations including:

- field mapping and air photo interpretation of the 1:250,000 Scale Geological Series by Earth Resources Australia Pty Ltd in 1981 (**Figure 4-4**);
- **1:100,000 Scale** Geological Series Rookwood Sheet 8851 First Edition 2001 (DNRM, 2001) (south of 1:100,000 Scale Geological Series Marlborough Sheet 8852) (**Figure 4-5**);
- the 2018 CQC Geological Model of the CQC Project area (**Section 4.2.2**); and
- transient electromagnetic (TEM) survey of the CQC Project area by Groundwater Imaging (2019) (**Attachment 5**) to support the separation and delineation of Cenozoic sediments.

4.1 STRUCTURAL SETTING

The CQC Project is located within the Early (or Lower) Cretaceous aged Styx Basin, which is superimposed on the Permo-Triassic aged Bowen Basin. Along with other Permo-Triassic aged Sydney and Gunnedah Basins and overlying Jurassic-Cretaceous Surat Basin in eastern Australia, the basins have been associated with coal exploration and mining for over a century, and with hydrocarbon exploration and production, particularly in the Bowen Basin and overlying Surat Basin succession in Queensland, for several decades (R.S. Othman, 2003).

East of the CQC Project, the Bowen Basin is bound by the Marlborough Block consisting of metamorphics of possibly Palaeozoic age and serpentinite. Laterite caps much of the serpentinite near Marlborough.

Extensive lateritization took place during the Tertiary period and particularly thick laterite profiles developed on the flat-lying, poorly consolidated Tertiary sediments (E.J. Malone, 1964). West of the CQC Project, the Bowen Basin is bound by the Connors Arch, a broad structure with the Connors Volcanics and pre-Permian intrusives exposed in the core (**Figure 4-5**) (E.J. Malone, 1964). The Lower Permian units (Carmila Beds) to the east generally dip away from Connors Arch at 20° to 40° but with local tight folding (E.J. Malone, 1964).

The position of CQC Project relative to the Bowen Basin is best described by the structural cross-section presented in **Figure 4-3[c]**, as well as the broader cross-section and diagrammatic relationship presented in **Figures 4-2[b] and 4-2[c]**.

4.1.1 Styx Basin

The Styx Basin is a small, Early Cretaceous aged, intracratonic sag basin that covers an area of approximately 300 km^2 onshore and 500 km^2 offshore. The Styx Basin probably developed by subsidence of the Strathmuir Synclinorium, an older feature containing Permian Bowen Basin strata. Styx Basin sediments lap onto Permian strata in the west but are faulted against them in the east[xiii].

The known coal bearing strata of the Styx Basin are referred to as the Styx Coal Measures. The Styx Coal Measures are preserved as basin infill in a half graben geometry which has an overall plunge to the north (CDM Smith, 2018e). A description of the Styx Coal Measures (and stratigraphy) is provided in **Section 4.2.1**.

4.1.2 Bowen Basin

The CQC Project is located in the eastern limb (extension) of the Bowen Basin, between the Connors Subprovince in the west, and to the east the Marlborough Province and Stoodleigh / Grantleigh Subprovinces (**Figure 4-1[a]**). As described in the draft *Regional Groundwater Chemistry Zones: Fitzroy-Capricorn-Curtis Coast and Burdekin-Haughton-Don Regions Summary and Results* (McNeil *et al*., 2018), the eastern extension of the Bowen Basin contains rare, Mesozoic aged coals.

The Bowen Basin eastern limb which underlays the CQC Project area and surrounds consists of three distinct structural (basal) elements: the Connors Arch (west); the Strathmuir Synclinorium (central); and Gogango Overfolded Zone (east) (**Figure 4-5**). The eastern limb extends from the Boomer Range in the south (**Figures 4-1[b] and 4-6[a-c]**).

Deposition in the Bowen Basin eastern limb commenced in the Lower Permian when the volcanics and sediments of the Lizzie Creek Volcanics and Carmila Beds accumulated over the area. The sea transgressed the area toward the end of deposition of these two units and they were succeeded by the marine fossiliferous Back Creek Group (Malone, 1964).

E.J. Malone (1964) also relevantly notes that:

> *The Back Creek Group in the southeast of the St Lawrence Sheet area does not exhibit the effects of periodic transgressions and regressions that are shown by the group throughout most of the Bowen Basin.*
>
> *Possibly the topography of this part of the depositional area was so rugged that small-scale epeirogenic movements or eustatic variations in sea level did not appreciably alter the depositional environment.*

Based on a review of available geological mapping by CQCPL's geologists (at various scales), it was noted that where specific members of the Back Creek Group were recognised (e.g. Boomer Formation), each was depicted as the formation understood at the time to be a part of.

Where unable to be differentiated, outcrop areas were broadly mapped as Back Creek Group, an all-encompassing group of Permian sedimentary rocks. Further description of the stratigraphy of the Permian Measures, including the Back Creek Group (and Boomer Formation), is provided in **Section 4.2.1**.

The Permian sequence of the Bowen Basin, and groundwater conceptualisation for the purposes of this assessment, is discussed in **Section 6.1.3**.

4.1.3 Strathmuir Synclinorium / Syncline

The Strathmuir Synclinorium[18] is an elongated north-trending structure occupied by the Carmila Beds and Back Creek Group (**Figure 4-2[a]**). Malone (1964) relevantly notes that:

> *The western limb of the synclinorium south of St Lawrence has some local tight folds and is complicated by the inlier of Connors Volcanics near Tooloombah homestead.*

The inlier of the Connors Volcanics is evident on the cross-section shown in **Figure 4-3[b],** from the 1:100,000 Scale Geological Series Marlborough Sheet 8852 (DNRMW, 2006).

The Strathmuir Syncline is delineated by 1981 mapping by Earth Resources Australia Pty Ltd on a 1:100,000 base map (**Figure 4-4**), based on field mapping, air photo interpretation and the 1:250,000 geological series sheet SF 55-12 St Lawrence.

4.1.4 Regional Faults (Styx Basin / Permian Measures of Bowen Basin Interface)

Regional faults are mapped at the interface of the Styx Basin and Permian Measures of the Bowen Basin, and most notably the Gogango Overfolded Zone to the east / north-east of the CQC Project toward the Marlborough Block (**Figure 4-5**).

Some regional faulting is also mapped in the areas further to the south-west of the CQC Project associated with the inlier of Connors Volcanics (**Figures 4-3[b] and 4-5**).

Of most relevance for the purposes of this groundwater assessment is the fault / interface to the east of the CQC Project. As shown on **Figure 4-3[e]**, the mapped fault throw is estimated to be greater than the thickness of the Styx Coal Measures (e.g. in order of hundreds of metres) and has been assumed accordingly in the conceptualisation in **Section 6.3.1**. Since development of the improved numerical groundwater model, CQCPL has since installed WMP31 east of the fault (drilled to a depth of approximately 200 m) and is discussed further in **Section 5.1.3**.

The regional tectonic setting of the Bowen Basin is largely compressive and as a consequence faults and folds are more likely to be hydraulic barriers than conduits to lateral groundwater flow (Arrow Energy, 2012). Consideration of the influence of regional faults in the numerical model structure and analysis is discussed in **Section 7.4.2**.

4.1.5 Local Faults and Discontinuities

To date no significant faults or dykes have been identified by CQCPL's geologists during exploration activities within the CQC Project open cut extent, nor during specific geological investigations undertaken by Cardno (2018) and AMEC (2018).

CDM Smith (2018f) relevantly notes that whilst no faults have been interpreted, the apparent undulations seen in the floor contours of the coal seams is considered small scale folding associated with the syncline in the area.

---

[18] Generally defined as a larger syncline upon which smaller folds are superimposed.

To the north of the CQC Project, it is documented in the Geological Survey Report prepared by the District Geologist (S.R.L. Shepherd, 10 February 1949) the existence of localised folding and faulting as follows (and shown on **Figure 3-13**):

> *In the workings of the Bowman State mine at least six faults over a horizontal distance of about 250 ft. [76.2 m] were encountered. These have a trend varying from north-south to north-west south-east. …*

4.2 OUTCROP GEOLOGY MAPPING

Outcrop geology mapping is presented on **Figures 4-1[a], 4-2[a] and 4-3[a]**, and is overlain in areas by Cenozoic and Tertiary sediments described in **Section 4.3**. A description of the stratigraphy of the Styx Coal Measures and basement formations are provided below.

4.2.1 Stratigraphy, Styx Coal Measures and Permian Measures

Styx Coal Measures [Kx or Kls]

The Styx Coal Measures are an isolated block of Lower Cretaceous sediments, unconformably overlying the Permian aged Back Creek Group. The Lower Cretaceous age assigned to the Styx Coal Measures was on the basis of fossil macroflora by Walkom (1919). Subsequent works on microflora (Cookson and Dettman, 1958) and on microfauna (Cookson and Eisenach, 1958) obtained from cores of the Tooloombah Creek bores supported this age (Malone, 1964).

Chong (1964) reported that based on one of the deepest drill holes in the Ogmore area at the time, the upper 250 m of the 365 m thick Styx Coal Measures was only considered to be coal bearing with the underburden barren and underlain by a basal conglomerate.

The stratigraphy of the CQC Project area is shown schematically on Figure 5-6 in CDM Smith (2018e) (**Figure 4-7**), and in a localised cross-section through the CQC Project Open Cut Extent (**Figure 4-8**), based on the following coal seam/ply nomenclature:

- Grey Seam (GR1 and GR2);
- Green Seam (GR Upper, GR Lower 1 and GR Lower 2);
- Red Seam (R Upper, R Lower);
- Pink Seam (P);
- Orange Seam (O Upper 1, O Upper 2 and O Lower);
- Yellow Seam (Y Upper 1, Y Upper 2, Y Lower);
- Blue Seam (B Upper 1, B Upper 2, B Lower 1 and B Lower 2); and
- Violet Seam (V Upper 1, V Upper 2, V Lower 1 and V Lower 2).

CDM Smith (2018e) states that the sequence of coal seams/plies are contained within a sequence of approximately 120 m of coal bearing strata. Seam splitting is common and seam thicknesses vary considerably where coalescing occurs. The Grey, Green and Orange Seams are characteristically coal ply groups that do not coalesce within the proposed mining area.

The Red Seam is reported by CDM Smith (2018e) as the most consistent in thickness and quality through the ML 80187 area, commonly exceeding two metres in thickness.

It is also noted that the Blue and Violet Seams may coalesce to form substantially thick seams in parts of the deposit, nevertheless all plies and coalesced seams demonstrate coal quality and seam thickness characteristics that are attractive mining targets (CDM Smith, 2018e). Indicative seam thickness statistics for the full sequence of the Early Cretaceous Styx Coal Measures as presented in CDM Smith (2018e) is repeated in **Table 4-1**. Indicative average thicknesses within the proposed mining area are also shown on **Figure 4-8**.

Beneath the coal seams, thick sandstone layers gradually rise to the west to form low hills. As noted by CQCPL's geologists and TEM survey (**Attachment 5**), sandstones are also visible in Tooloombah Creek.

Table 4-1
Indicative Average Coal Seam/Ply Thicknesses for the Styx Coal Measures

Seam	Ply	Indicative Average Thickness	Combined Seam Thickness Indicative Average
Grey	GR1	0.42 m	0.79 m
	GR2	0.37 m	
Green	GR Upper	0.34 m	0.90 m
	GR Lower 1	0.37 m	
	GR Lower 2	0.19 m	
Red	R Upper	0.81 m	1.52 m
	R Lower	0.71 m	
Pink	P	0.16 m	0.16 m
Orange	O Upper 1	0.33 m	0.95 m
	O Upper 2	0.26 m	
	O Lower	0.36 m	
Yellow	Y Upper 1	0.64 m	1.31 m
	Y Upper 2	0.30 m	
	Y Lower	0.37 m	
Blue	B Upper 1	0.56 m	2.17 m
	B Upper 2	0.71 m	
	B Lower 1	0.53 m	
	B Lower 2	0.37 m	
Violet	V Upper 1	0.36 m	1.31 m*
	V Upper 2	0.18 m	
	V Lower 1	0.43 m	
	V Lower 2*	0.34 m	

Source: After Table 5-7 in CDM Smith (2018e).
*Noted that Table 5-7 in CDM Smith (2018e) includes two Violet Lower ply statistics and therefore has not been repeated nor included in the total thickness.

Back Creek Group [Pb] (including the [Boomer Formation] [Pbm or Puu])

The Back Creek Group described in the Bowen Basin is lithologically variable, regionally developed, and comprises four subgroups: Tiverton; Gebbie; Blenheim; and Exmoor (URS, 2012). The Back Creek Group consists of quartzose to lithic sandstone, siltstone, carbonaceous shale, minor coal and sandy coquinite (NTEC Environmental Technology, 2011).

The major coal seams in the Bowen Basin are in the German Creek Coal Measures at the top of the Back Creek Group and is evident at the Middlemount Coal Mine (AGE Consultants, 2019).

The Back Creek Group is generally considered to be a regional scale confining unit (or hydraulic basement) of the Bowen Basin. Shallow unconfined groundwater can occur in outcrops and subcrops along the east and west margins of the Bowen Basin (Coffey, 2014).

The Back Creek Group around the Broadsound Range and east of the Connors Range includes some primary volcanics as well as abundant volcanic detritus. The lithological changes which distinguish the subgroups within the Back Creek Group in other areas are not recognisable in this area. Only the Boomer Formation is mapped as a separate formation; the remainder is mapped as undifferentiated Back Creek Group, though the faunas indicate the presence of equivalents of the Tiverton Subgroup and, in a few places, of the Gebbie Subgroup (Malone, 1965).

The depth to the top of the Back Creek Group varies across the Styx River catchment. Three exploration drill holes logged by Arrow Energy N.L. (2005; 2007a; 2007b) in the vicinity of Ogmore, north of the CQC Project provide depths to the top of the Permian sequence (**Section 3.4.6; Table 3-8**).

An additional drill hole (WMP31) has been drilled to the north-east/east of the CQC Project proposed open mining extents and the geological and geophysical logs in the Back Creek Group presented in **Attachment 4**.

The Back Creek Group and Boomer Formation is also described in detail in Withnall *et al.* (2009). Indicative thicknesses are reported to range up to 1,000 m with apparent dramatic thickness increase eastward from the Connors Arch at about the western edge of the Gogango Overfolded Zone.

The Upper and Lower Back Creek Group thicknesses are also noted as difficult to estimate in Withnall *et al*. (2009) however based on the dips available, width of outcrop and exposure sequences is estimated to probably be ~300 m and ~250-300 m thick respectively.

Boomer Range

Malone (1965) notes that the Boomer Formation is apparently the lateral equivalent of the Blenheim Subgroup which is mapped elsewhere in the Bowen Basin (e.g. east of the Middlemount township) (AGE Consultants, 2018). The Boomer Formation is a northern extension of the Boomer Range evident on the Rookwood 1:100,000 Geological Series Map 8851 (south the CQC Project). Cross-section A-B shows the Boomer Range and the Boomer Formation subcrop on the eastern slopes (**Figures 4-6[a-c]**).

Withnall *et al*. (2009) relevantly notes:

> *In the Gogango Overfolded Zone, there is some confusion between what was shown as Boomer Formation and undivided Back Creek Group on previous maps. However, in the western part of Rookwood* [1:100,000 Geological Series Map]*, the distinction is relatively clear. The undivided Back Creek Group consists dominantly of massive cleaved mudstone, whereas the Boomer Formation contains abundant lithic sandstone as well as cleaved mudstone and is radiometrically distinct (pink or brown on RGB composite images, rather than white, due to lower thorium and uranium responses — see Figure 66). … . On aerial photographs, the Boomer Formation in western Rookwood and Marlborough* [1:100,000 Geological Series Maps] *is characterised by conspicuous strike ridges produced by differential weathering of the sandstone and mudstone.*

Carmila Beds [Pc] (or Lizzie Creek Volcanics Group)

The Carmila Beds and Lizzie Creek Volcanics are laterally equivalent. Both include marine calcareous sediments and volcanics at the top which contain similar faunas, and both are succeeded, possibly conformably, by the basal beds of the Back Creek Group. In places, the Back Creek Group has disconformably overlapped the Carmila Beds or the Lizzie Creek Volcanics and directly overlies the Connors Volcanics (Malone, 1965) (**Figure 4-4**).

The name Lizzie Creek Volcanic Group is now applied to all of the rocks that lie between the Connors Volcanic Group and the Back Creek Group, the lowermost part of the Bowen Basin succession (Withnall *et al*., 2009).

Wongrabry Beds (Pvw) and Glenprairie Beds (CPp)

The Wongrabry Beds and Glenprairie Beds are mapped in the far east of the Wellington Creek catchment associated with the Mt Wellington range. The Wongrabry Beds are predominantly volcanolithic sandstone and polymictic conglomerate; subordinate basalt or andesite and rhyolite; rare limestone and coquinite.

The Glenprairie Beds comprise mainly fine to coarse-grained feldspatholithic sandstone and minor granule conglomerate, mudstone and siltstone; local felsic volcanoclastic rocks (DNRMW, 2006). These rocks were previously mapped as Carmila Beds (Withnall *et al.*, 2009).

4.2.2 Geological Cross-sections

Conceptual geological cross-sections based on an aggregated coal seams sourced from the 2018 Geological Model provided by CQCPL are shown on **Figure 4-9**.

More broadly, regional conceptual cross-sections for the Styx Coal Measures and basement (i.e. Permian sequence) based on regional geology mapping is shown on **Figures 4-2[b], 4-3[b], 4-3[c] and 4-6[b]**.

Historic geological cross-sections are also presented on **Figures 3-15[b], 3-16 and 3-17**.

At a local scale, detailed cross-sections adjacent to the Bruce Highway prepared as part of the *Central Queensland Coal Project Pits Adjacent to Bruce Highway – Slope Stability Assessment* (Cardno, 2018) are also included in Appendix 4b to the SEIS (Version 2).

4.3 SURFICIAL GEOLOGY (CENOZOIC SEDIMENT) MAPPING

The extents of Cenozoic sediments across the CQC Project and surrounds has been mapped at varying scales (and accuracies) including:

- **1:2,000,000 Scale** (DNRM, 2012) (**Figure 4-1**);
- **1:250,000 Scale** (Malone, 1965) (**Figure 4-2**), including subsequent field mapping and air photo interpretation by Earth Resources Australia Pty Ltd in 1981 (**Figure 4-4**); and
- **1:100,000 Scale** (DNRMW, 2006) (**Figure 4-3**).

At a local scale, mapping of Cenozoic sediments on **Figure 4-3** is generally consistent with the TEM survey results (**Attachment 5**) to support the concept for separation and delineation of Cenozoic sediments in the numerical groundwater model (**Section 7.4.1**) and is discussed in **Section 4.3.1.**

Review of 274 shallow drill hole logs (to approximately 30 m) provided by CQCPL's geologists was also undertaken for select comparison with available survey and groundwater datasets.

For the purposes of alluvium descriptions below, it is noted that the Quaternary period is the most recent of the three periods of the Cenozoic era (Paleogene, Neogene and Quaternary), and is divided into two epochs:

- Pleistocene; and
- Holocene.

The Pleistocene epoch is better known as the period of the ice age whereby repeated glaciations occurred across the earth for more than 2 million years, up to last glacial period (approximately 11,500 years ago). The Holocene followed and includes up to present day. Further discussion is provided in **Section 4.6.1**.

4.3.1 Quaternary Alluvium (Qa) (Holocene)

The 1:100,000 Scale mapping (DNRMW, 2006) of Qa (Holocene) units in the vicinity of the CQC Project demonstrates that the Qa units comprising clay, silt, sand, gravel; floodplain alluvium is generally confined to the watercourses and local drainages, and is differentiated from the Qpa units comprising sand, mud and gravel; alluvium on higher terraces (**Figure 4-3**).

It is noted that Earth Resources Australia Pty Ltd mapping in 1981 had previously limited the mapped Qa units to be downstream of the Ogmore Road Bridge (**Figure 4-4**).

The results of the TEM survey mapping (**Attachment 5**) were generally consistent with the 1:100,000 Scale mapped Qa units with some localised differences (and some areas potentially associated with outcropping sandstone bedrock which is discussed further below). In particular, the low resistivity areas mapped along the Styx River at the Monopoly property at BH16 and BH01X (i.e. with lower salinity water i.e. recharge from fresh surface water sources [*NB: BH20 is an existing landholder bore in use at the location*]) correlated well with the Qa unit (**Plate 4-1**), thus supporting the concept for application of higher hydraulic conductivities relative to the adjacent Qpa unit discussed further in **Sections 6.0 and 7.7.3**.

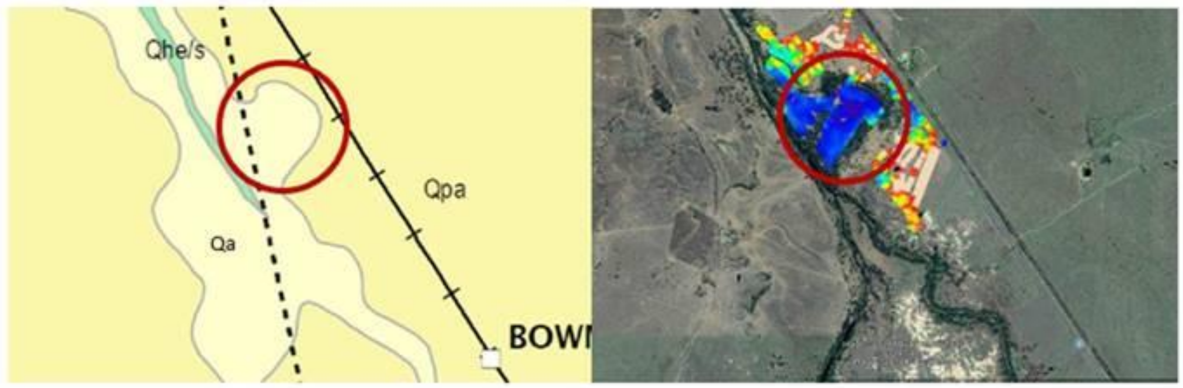


Plate 4-1
Comparison of TEM Survey Results with 1:100,000 Scale Mapped Qa Units – Tooloombah Creek
[*Source: After DNRMW (2006), CDM Smith (2018e) and Groundwater Imaging (2019)*]

Specific consideration of the TEM results was made during the numerical model build and application discussed in **Section 7.4.1.** Notably, resistivity contrasts in localised areas near Tooloombah Creek where the sandstone bedrock outcrops at the gauging station rock bar control (**Plate 4-2**) were identified by Groundwater Imaging (2019) and therefore considered.

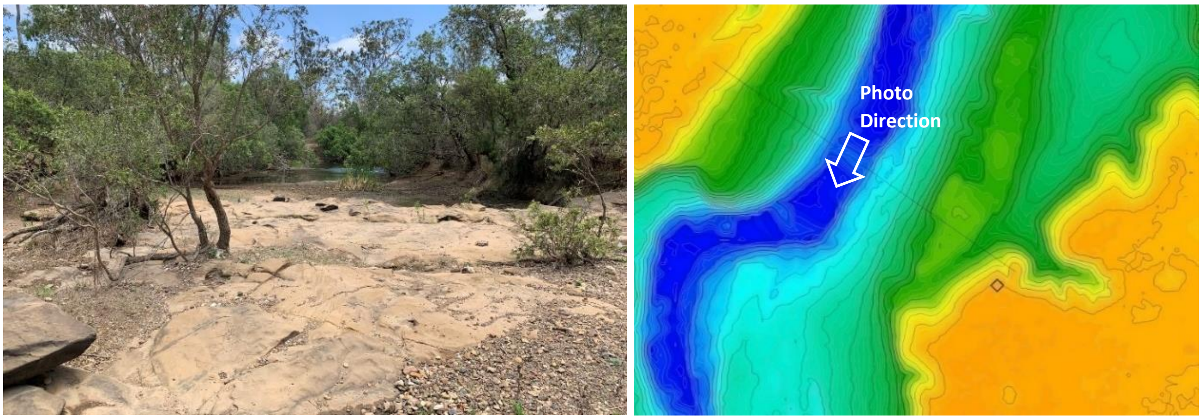


Plate 4-2
Sandstone Bedrock at Gauging Station (as noted in TEM Survey Results) – Tooloombah Creek
[*Source: ALS, 2019 (Topographic Contours)*]

The TEM survey report relevantly concludes (**Attachment 5**):

> *Based on the AgTEM survey results, it is recommended that future groundwater modelling should recognise the more permeable 'Holocene' alluvium is restricted to rare deep cut infills. The mapped 'Pleistocene' alluvium is thought to be over the Early Cretaceous coal measures however the surface weathering profile seems to make the two indistinguishable. Considering that at places there is sandstone at the surface which appears it is Early Cretaceous and that weathering extends even beneath such solid layers in the drill holes logged, the surface weathering profile should be considered as a hydrological unit separate from the 'Holocene' sands found in the creeks and in rare infilled creeks evident in the AgTEM data. …*

The results of the TEM survey were also considered by Fluvial Systems Pty Ltd (2020) when considering the mapped units in a geomorphic context and is discussed in **Section 4.6**.

4.3.2 Quaternary Pleistocene Alluvium (Qpa)

The 1:100,000 Scale mapping (DNRMW, 2006) of Qpa units (comprising sand, mud and gravel; alluvium on higher terraces) in the vicinity of the CQC Project area (**Figure 4-3**) shows that Pleistocene age sediment overlies much of the Styx Coal Measures.

In addition to the available mapping, CQCPL's geologists conducted a review and analysis of:

- geology logs and downhole geophysics condensed into scaled depictions of lithology to approximately 30 m depth showing: rock type; grain size; colour (including lateritic features), extent of weathering; natural gamma and density traces;
- LiDAR terrain model to characterise stream profiles including cross-sections generated to understand physiographic characteristics of the banks, channels and flow paths; and
- LandSat Imagery (641).

The analysis was considered during the review and development of the conceptual groundwater model in **Section 6.3**. Notably, clay was by far the most frequently encountered material within the Quaternary age sediment across the CQC Project area. Further background to the Cenozoic era sediments and their formation is provided in the Fluvial Geomorphology Assessment (**Attachment 6**) and summarised in **Section 4.6**.

4.3.3 Colluvium / Alluvial Fan Deposits (Qr, Qf > Kx)

Colluvium / Alluvial Fan Deposits are locally mapped west and south-west of the CQC Project at the lower slopes of the elevated landforms associated with Mt Mamelon which topographically drains a small unnamed tributary northward toward Tooloombah Creek.

4.3.4 Quaternary Holocene Estuarine Alluvium (Qhe/s, Qhe/m, Qhcm)

Areas mapped as Quaternary Holocene Estuarine Alluvium are largely confined to the estuarine areas of the Styx River (downstream of the Ogmore Road bridge crossing) and the Broad Sound Fish Habitat Area (FHA-047).

4.3.5 Tertiary Sediments (Ta, Td, TQr)

Tertiary units are mapped on the 1:250,000 Geological Series mapping to the south-east of the CQC Project associated with the elevated areas south of Kooltandra toward Marlborough, which are reported as being displaced by normal faulting and in the Gogango Overfolded Zone (Malone, 1964).

4.4 SOILS AND SOIL LANDSCAPE MAPPING

A description of soils and soil landscape mapping sources (including targeted field assessments) are presented in CDM Smith (2018e). Within and surrounding the CQC Project which drain to Deep Creek and downstream Tooloombah Creek and the Styx River, the Atlas of Australian Soils (Northcote *et al*. 1960-68) has mapped four (4) predominant soil landscapes and associated soil types as follows (ASRIS as presented on Qld Globe):

- CC32: Gently undulating or level plain [Vertosols in general - grey self-mulching cracking clays (uniform fine cracking, smooth faced pedals, grey clay horizon underlain by grey/mottled clay)];
- VD3: Gently undulating slightly elevated plains [Sodosols in general - hard pedal mottled-yellow duplex soils (duplex yellow-grey, hard setting A horizon, A2 horizon sporadic bleached, alkaline pedal mottled B horizon)];
- UB89: Moderate to strongly undulating lands with occasional low hilly areas [Sodosols in general - hard pedal mottled-yellow duplex soils (duplex yellow-grey, hard setting A horizon, A2 horizon conspicuous bleached, neutral pedal mottled B horizon)]; and
- MW26: Strongly undulating lands with some high narrow ridges [Kandosols in general - red massive earths (gradational red, A2 horizon non-bleached, acid massive earth whole column B horizon)].

In total, 145 individual soil profiles (H001-H134; and SS01-SS11) have previously been recorded as part of detailed soil landscape and soil type sampling across the CQC Project area and surrounds (CDM Smith, 2018e; Horizon Soil & Evaluation, 2014) and is relevantly discussed in **Section 5.1.1**.

4.4.1 Acid Sulfate Soil Potential

A description of potential acid sulphate soils is presented in the SEIS Version 3 (Orange Environmental Pty Ltd, 2020). The Australian Soil Resource Information System (ASRIS) shows that in terms of acid sulfate soil potential, the CQC Project area and immediate surrounds are classified as either:

- BN(P4) – Low Probability of Occurrence; or
- Co(P4) – Extremely Low Probability of Occurrence.

As concluded in the SEIS Version 3 (Orange Environmental Pty Ltd, 2020), the geology and risk mapping in the area of the CQC Project does not support the presence of acid sulfate soils, either within the surface disturbance footprint or the maximum extent of predicted groundwater drawdown (**Section 8.5**). Nevertheless, monitoring and management strategies and appropriate contingencies, as outlined in the draft EMP (Appendix A12 to SEIS Version 3), would be adopted and implemented should unexpected conditions be encountered.

4.5 GEOCHEMICAL ABUNDANCE AND GEOCHEMISTRY

A detailed assessment of the geochemical characteristics of the rock geology to be excavated as waste rock (i.e. overburden and interburden) as well as other representative materials (i.e. coarse and fine rejects removed during the crushing, screen and washing of coal) at the CQC Project is provided in Chapter 8 of the SEIS Version 3 (Orange Environmental Pty Ltd, 2020) and is supported by a technical report by RGS Environmental (2020). Analysis of solution extracts (i.e. water quality) was also completed and a concise summary of relevant outcomes is provided below.

The assessment of waste rock and other representative materials was completed based on the geochemical analysis by RGS Environmental in 2012 on a total of 174 discrete samples. An additional 21 samples of other materials representative of coarse and fine rejects (i.e. coal, and immediate roof and floor rock) was analysed by ALS in 2018.

Static laboratory testing was completed on individual and composite samples including:

- pH and EC (1 parts rock : 5 parts water);
- acid-base analysis (including net acid producing potential [NAPP] from maximum potential acidity [MPA][19] and acid neutralising capacity [ANC]);
- multi-element composition (rock and solution extract); and
- cation exchange capacity (CEC) including exchangeable sodium percentage (ESP).

Kinetic leach column laboratory testing was also completed by RGS Environmental in 2012 on composite samples for:

- pH and EC;
- acidity, alkalinity and net alkalinity;
- multi-element composition (solution extract).

The multi-element composition analysis on rock showed that when compared to the average crustal abundance (Bowen, 1979), only one composite sample recorded a geochemical abundance index (GAI) of zero or positive, which could suggest some (albeit slightly) enrichment of iron (Fe), manganese (Mn), arsenic (As) and zinc (Zn) in the local rock geology.

The kinetic leach column laboratory testing and multi-element composition analysis on solution extracts from the composite samples indicated that dissolved concentrations of the following analytes, when compared to relevant assessment criteria, also warranted further consideration:

- aluminium (Al);
- arsenic (As);
- molybdenum (Mo);

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[19] From total sulphur analysis. Chromium reducible sulphur also tested on select samples.

- selenium (Se); and
- vanadium (V).

CDM Smith (2018k) relevantly concluded that metal / metalloid concentrations in water extracts by RGS Environmental in 2012 were generally consistent across composition samples and therefore likely consistent with existing concentrations within the regional geology and associated aquifer. Further comparison and discussion is provided in **Sections 5.5 (Tables 5-10, 5-11, 5-14 and 5-15) and 6.2 (Table 6-3)**.

Importantly, the acid-base analysis presented by CDM Smith (2018k) classifies the waste rock as acid consuming (i.e. not generating) and likely to remain pH neutral to alkaline following excavation, and therefore dissolution of heavy metals in an acidic environment is unlikely (CDM Smith, 2018k).

The kinetic leach column laboratory testwork results for net alkalinity and residual ANC indicate that the alkalinity continued to be at or greater than the initial values and the rock could be expected to continue to produce alkalinity commensurate with the high average ANC of the static laboratory testwork results. These alkaline water quality results appear to be consistent with the elevated baseline groundwater quality monitoring results for pH at the CQC Project and surrounds (**Section 5.5**).

Based on the static and kinetic laboratory testwork undertaken, the salinity of the waste rock and other representative materials was moderate to low (with decreasing salinity) and relatively stable over the testing period (CDM Smith, 2018k).

Sodicity levels (in the form of ESP) was very high (28.9% to 42.7%) (CDM Smith, 2018k) and appeared to be generally consistent with site observations of eroded areas (e.g. adjacent to Deep Creek) and of *in-situ* aquifer testing of low permeability sequences (**Section 5.6.2**).

4.6 GEOMORPHOLOGY

A fluvial geomorphology assessment has been prepared separately by Fluvial Systems Pty Ltd (2020) (**Attachment 6**) and includes a baseline component describing the geology and deposition processes in the Styx Basin with particular emphasis on the Pleistocene and Holocene epochs. Relevant excerpts are summarised below.

4.6.1 Surficial Deposition Processes

The label Qh relates to the Holocene epoch (<11,700 years). This material is associated with the second of two periods of Quaternary alluvial deposition in coastal streams within alluvial valleys. Active Holocene alluvium is usually recognised by landform patterns associated with current stream channels and over-bank stream flow. Variants are mapped and labelled in the Styx River catchment as Qhe/s, Qhe/m and Qhcm. These are all estuarine sediments.

Undifferentiated Quaternary alluvium (Qa) comprises active Holocene alluvium (Qha) and recent Pleistocene alluvium (Qpa). Undifferentiated means that it was not possible to specify finer age divisions. In the Styx River catchment there is no unit mapped and labelled Qha. Rather, where Qha would be expected, the unit is labelled Qa (undifferentiated) with lithology described as clay, silt, sand, gravel; floodplain alluvium.

The label Qpa relates to the recent Pleistocene epoch (11,700 – 140,000 years). This material is associated with the first of two periods of Quaternary period alluvial deposition in coastal streams within alluvial valleys, now slightly elevated and/or prior and abandoned streams. During the early interglacial part of the recent Pleistocene (140,000 – 120,000 years) sea levels were 4 to 6 metres higher than the present level (Wilson and Taylor, 2012).

Under these conditions, wide tracts of alluvial deposits filled the valleys, and a series of river terraces was developed. The glacial cycle during the recent Pleistocene (120,000 – 20,000 years) was associated with sea levels 80 to 140 metres below present sea level. During this time, rivers and creeks cut deep trenches through the previously deposited fluvial, estuarine and marine deposits. As sea level rose towards the present level, sediments were re-deposited within the eroded trenches. Present sea level was reached about 6,000 years ago, and since then the level has remained constant to within a few metres (Lambeck and Nakada, 1990). Sea level rises of up to 1.5 metres above the current sea level during the Holocene would have been associated with further deposition of sediments into the incised Pleistocene alluvium corridor, while subsequent falls in sea level would have been associated with incision (Wilson and Taylor, 2012). The lithology of Qpa is described as clay, silt, sand, gravel; flood-plain alluvium on high terraces with the only lithological difference with Qa being reference to its occurrence on high terraces.

Soil developed from Pleistocene alluvium commonly has a higher degree of profile development than that developed from Holocene alluvium. However, these landscapes usually grade into each other making it difficult to distinguish a hard boundary. In some places the recent Pleistocene alluvium can be inundated by flood events from creeks draining the local uplands. These difficulties have led to alluvial deposits in river corridors being mapped as Qa (140,000 years to present), which covers the Holocene (Qha) and the recent relict sediments of the associated Pleistocene alluvium (Qpa) (Wilson and Taylor, 2012).

The fluvial geomorphology assessment (Fluvial Systems Pty Ltd, 2020) (**Attachment 6**) uses topographic indices to define a morphological boundary between Qpa and Qha, recognising that alluvium is eroded material that has been transported far from its source and deposited by a stream in a valley floor. It is recognised that in a geomorphic context ‘unconsolidated’ alluvium is a more permeable deposit of sand and gravel that could contain alluvial aquifers, while ‘consolidated’ alluvium is considered a deposit of silt and clay with relatively lower permeability, and little prospect for containing alluvial aquifers.

Floodplains are always composed of alluvium, but alluvium does not always contain aquifers with significant reserves of groundwater. Thus, the geomorphic terms for “unconsolidated” and “consolidated” alluvium differ from the hydrogeological terms when referring to unconsolidated and consolidated aquifers, and application of trigger thresholds (2 m and 5 m) defined in the *Water Act 2000*, described later in **this Report**.

4.6.2 Bed and Bank Stability of Watercourses

Bed and bank dimensions, slopes, flow and erosion conditions in May 2017 are documented in Table 9-24 of CDM Smith (2018h) for:

- Deep Creek (De1, De2, De3 and De4);
- Tooloombah Creek (To1, To2, To3x and St1); and
- Barrack Creek (Ba1x).

Other relevant observations made by CQCPL’s geologists at Deep Creek and Tooloombah Creek are as follows:

- The deepest parts of the watercourses have incised into the Quaternary Pleistocene sediment and weathered Early Cretaceous Styx Coal Measures.
- There are no levee banks formed along the watercourse margins, indicating that overbank flooding is rare.
- The terraces formed on either side of the watercourses are probably re-worked sediment.
- Tooloombah Creek is ‘mature’ downstream of the confluence of Deep Creek as evidenced by the degree of meandering and the common relect ‘ox-bow’ waterholes and channels that have silted up. [*NB: and is consistent with the TEM survey results [**Section 4.3.1**] and groundwater quality monitoring at BH16 and BH01X*]

The Waterway Barrier Works Assessment (CQCPL & FCPL, 2018) (Appendix A21 to SEIS Version 3) identified that a number of the local drainage features across the site include depressions (i.e. no defined channel) with relatively steep eroded gully which did not have any defined bed or banks or provide any potential pooled areas before draining to Deep Creek.

Further description of the bed and bank stability of watercourses at the CQC Project and surrounds is provided in Fluvial Systems Pty Ltd (2020) (**Attachment 6**).

Downstream of the CQC Project, comparisons of topography, sinuosity and simulated groundwater tables (**Section 5.4.1**) are also presented in **Figure 4-10**. As shown, there is a topographic low at the confluence of Granite Creek, Montrose Creek and the Styx River, immediately upstream of the Broad Sound Fish Habitat Area (Plan FHA-047) (**Figure 3-5**) which results in a lower water table elevation.

5.0 GROUNDWATER DATASETS AND DEPENDENT ASSETS (INCLUDING GROUNDWATER CONNECTIVITY AND DEPENDENCY)

5.1 GROUNDWATER MONITORING AND INVESTIGATIONS – ML 80187, ML 700022 AND SURROUNDS

The groundwater monitoring network installed within ML 80187, ML 700022 and surrounds is extensive and has been progressively developed as part of initial exploration and groundwater investigation programs (i.e. 2010-11[20], 2011-12 and 2014[21]), through to targeted and detailed groundwater investigations, bore census and baseline monitoring network installations (and extensions) in 2017 and 2018, and supplementary groundwater investigations and continued baseline groundwater monitoring in 2019-20 to support improvements to the groundwater modelling and assessments and future validation, including more recently (**Attachment 4**):

- continued monthly baseline groundwater level monitoring (and groundwater sampling for quality analysis) at the 2017 WMP Series (WMP02, WMP04, WMP04D, WMP05, WMP06, WMP07, WMP08, WMP08D, WMP09, WMP10, WMP11, WMP11D, WMP12, WMP13, WMP14, WMP15);
- establishment of ongoing periodic (e.g. monthly) baseline groundwater level monitoring (and groundwater sampling for analysis) at the 2018 WMP Series (WMP16, WMP16D, WMP17, WMP17D, WMP18, WMP18D, WMP19, WMP19D, WMP20, WMP20D, WMP21, WMP22A, WMP22B, WMP22C, WMP23A, WMP24, WMP25, WMP26, WMP27, WMP28, WMP29A, WMP29B, WMP29C, WMP29D, WMP29E, WMP30A, WMP30B, WMP30C);
- continued monthly baseline groundwater level monitoring (and groundwater sampling for quality analysis) at select landholder bores (BH01X and BH16);
- regular (generally every 2nd day) on-site groundwater level recordings (and field groundwater quality testing) in select WMP Series (WMP04, WMP10, WMP22A, WMP24), exploration drill hole (STX1205L) and select waterholes / pools on Tooloombah Creek (Easting 772174; Northing 7489156) and Deep Creek 1 (Easting 774721; Northing 7485632) and Deep Creek 2 (Easting 775987; Northing 7485672) undertaken as part of the AMEC (2019) groundwater investigation;
- continuous datalogging of alluvial groundwater levels in groundwater bores responsive to stream or flood recharge in Deep Creek (WMP05) [paired with new Gauging Station No. 330452], Tooloombah Creek (WMP04) [paired with new Gauging Station No. 330451] and the Styx River (WMP29A) [for comparison with Broad Sound tides and local observations at Ogmore Road Bridge crossing]; and
- installation of a new VWP (WMP31) targeting the basement aquifers to the north-east (and east of the regional fault) targeting the Styx Coal Measures basement (i.e. Permian Measures – Back Creek Group).

The groundwater monitoring network as well as initial exploration drill holes, groundwater investigation programs and landholder bore census information is shown collectively on **Figures 5-1[a], 5-1[b], 5-1[c] and 5-2**.

In addition to the above, several additional site-specific groundwater investigations have been undertaken in 2019 to support the groundwater monitoring datasets including:

- transient electromagnetic (TEM) survey of groundwater associated with surficial geology (Groundwater Imaging, 2019) (**Attachment 5**);

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[20] Opportunistic groundwater level records in exploration drill holes STX073C, STX096C and STX145C.

[21] *Groundwater Investigations for the Styx Trial Pit* (AMEC, 2014).

- open end permeability and packer testing at two exploration drill holes STX1901 and STX1902 (AMEC, 2019) (**Attachment 7**); and
- core sampling from two exploration drill holes STX1812 and STX1903 and laboratory permeability testing (GES, 2020) (**Attachment 9**).

The results of the site-specific groundwater investigations are described in further detail in **Sections 4.3 and 5.6**. A summary of relevant groundwater datasets (to describe the groundwater connectivity and dependent assets) is provided in the following sub-sections. For ease of reference herein, the groundwater datasets are separated based on geology types and potential groundwater dependent assets.

5.1.1 Drill Logs and Standpipe Bores – Cenozoic Deposits (Quaternary Holocene Estuarine Alluvium, Quaternary Alluvium and Quaternary Pleistocene Alluvium / Regolith)

Cenozoic (or Cainozoic) deposits include the system of rocks deposited during the most recent geological era (i.e. 66 million years to date) and comprises the Quaternary and Tertiary periods. For the purposes of this groundwater assessment (for refined assessment of GDEs), the following analysis of available groundwater datasets for the drill logs and standpipe bores in the mapped Cenozoic sediments are generally based on the detailed (1:100,000 scale) surficial geology types consistent with **Section 4.3**, including:

- Quaternary Holocene Estuarine Alluvium (e.g. Qhe/s, Qhe/m, Qhcm);
- Quaternary Alluvium [Upper] (e.g. Qa); and
- Quaternary Alluvium [Lower] (e.g. Qa, Qpa) and Regolith (including Colluvium / Alluvial Fan Deposits [Qr, Qf > Kx], and older units).

It is recognised that within and in the immediate surrounds of the CQC Project there are no mapped Tertiary units (Malone, 1964). The nearest mapped Tertiary units (Ta, Td, TQr) are located more than 10 km to the south-east of the mine tenements (**Section 4.3.5**).

Details of all available groundwater measurement points in mapped Cenozoic deposits are provided in **Table 5-2** and **Attachment 4 (Tables A4-1 and A4-2)**. Corresponding hydrographs are provided in **Attachment 8 (Graphs A8-1 to A8-20)** where temporal datasets are available.

As described in **Section 4.4**, detailed soil landscape and soil type sampling has previously been conducted across the CQC Project area and surrounds, and included 145 individual shallow soil profiles within the mapped Cenozoic deposits and Regolith, comprising:

- 28 soil profiles in mapped Qa units;
- 101 soil profiles in mapped Qpa units;
- 2 soil profiles in mapped Qr, Qf > Kx units;
- 2 soil profiles in mapped Tertiary (Tb) units;
- 4 soil profiles in mapped Early Cretaceous (Kx) unit outcrops; and
- 8 soil profiles in mapped Permian (Pb) unit outcrops.

In 2018, several shallow drill logs constructed between 2010 and 2014 were also reviewed along the alignment of the Bruce Highway by Cardno (2018). Relevant log depths and characteristics recorded at each drill hole are provided in **Table 5-1**.

Table 5-1
Geotechnical Assessment Drill Holes in Mapped Cenozoic Deposits Along Bruce Highway

Measurement Point	Ground Elevation	Surficial Log Depth (Weathering)	Recorded Characteristics
STX050C	33.7 mAHD	24.7 mbgl	Claystone (to 19 mbgl)
STX080	33.1 mAHD	25.1 mbgl	Clay – Orange Brown / Mudstone (to 19 mbgl)
STX113CR	32.9 mAHD	25.1 mbgl	Clay – Brown Sticky (to 11 mbgl)
STX124	32.4 mAHD	26.6 mbgl	Clay / Silt / Sand / Mudstone (to 25 mbgl)
STX126B	37.2 mAHD	11.9 mbgl	Clay – Brown (to 11.9 mbgl)
STX127	37.2 mAHD	16.8 mbgl	Soil / Clay – Red to Brown (to 15 mbgl)
STX132C	31.5 mAHD	19.4 mbgl	Not Logged
STX120	34.1 mAHD	23.5 mbgl	Clay / Sand – Brown (to 19 mbgl)
STX505	35.2 mAHD	28.5 mbgl	Sand – Medium Brown (to 28 mbgl)

Source: After Cardno (2018) and AMEC (2017).

There are currently 15 standpipe groundwater monitoring locations at the CQC Project area and surrounds which are screened (predominantly) in Cenozoic deposits. In addition, groundwater level measurements have been recorded at another 10 private landholder bores which are inferred as being in Cenozoic deposits based on location and total depths.

All available groundwater level datasets are presented graphically for Cenozoic deposits in **Attachment 8 (Graphs A8-1 to A8-20)**, and the statistical average (based on available datasets) presented in **Table 5-2** for relative comparison.

The Quaternary (Holocene) Estuarine Alluvium groundwater levels generally range up to approximately 3.5 mAHD in the lower reaches of the Styx River (i.e. WMP29A). Further upstream along the Styx River (at the Ogmore Road Bridge), the Quaternary Alluvium groundwater levels are relatively higher to approximately 5 mAHD and above (i.e. BH04, BH01X, BH16). It is however expected that some localised drawdown and corresponding fluctuations in groundwater levels at the upstream locations (BH01X and BH16) could be as a result of an existing landholder groundwater bore in use at BH20 for stock watering.

In line with cumulative rainfall residual trends, recorded groundwater levels show a gradual decline in groundwater levels in the Cenozoic deposits during 2018 and 2019 **(Attachment 8**).

In the vicinity of the confluence of Tooloombah Creek and Deep Creek, the Quaternary Alluvium groundwater levels are again higher (at approximately 10 mAHD; WMP05), demonstrating an existing hydraulic gradient from the areas immediately downstream of the CQC Project toward the mid and lower (estuarine) mouth of the Styx River, and consistent with cumulative rainfall residual trends, show a gradual decline in groundwater levels since December 2017. Thus, indicating the recharge mechanism (from rainfall runoff to watercourses and drainage lines) is then likely toward the associated alluvium (i.e. losing conditions). Notably, WMP21 has also been recorded dry.

The recorded groundwater levels (greater than 50 mAHD) at BH29 (Neerim 1) is recorded in the mapped Quaternary Alluvium in the upper catchment of Deep Creek, several kilometres upstream of the CQC Project.

Table 5-2
Groundwater Measurement Points in Mapped Cenozoic Deposits

Measurement Point	SWL (mAHD)*	Measured Change# If Greater Than 0.5 m	Comments
Quaternary Holocene Estuarine Alluvium (e.g. Qhe)			
WMP29A	3.4	-	Continuous Datalogger installed in October 2019.
BH05X	2.4	-	Landholder Bore – Damaged during Cyclone Debbie.
BH06X	1.9	-	Landholder Bore – Poor condition, used previously to mix for concrete batching. Not in use^.
BH37	Dry~	-	Landholder Bore – Riverside 1. Not in use^.
Well01	2.1	-	Landholder Well – In use^.
Quaternary (Holocene) Alluvium [Upper] (e.g. Qa)			
WMP05	9.9	0.5	Continuous Datalogger installed in September 2019. Reflecting CRD Decline.
WMP21	Dry	-	Records at drill hole base.
BH01X	4.7	0.7	Landholder Bore - Not in use^. BH20 used nearby for stock watering.
BH16	5.2	0.9	Landholder Bore - Not in use^. BH20 used nearby for stock watering.
BH04	4.0	-	Landholder Bore - Windmill for stock watering.
BH29	55.0	-	Landholder Bore - Not in use^.
Quaternary Alluvium [Lower] (e.g. Qa, Qpa) / Regolith			
WMP02	8.2	-	Northern Extent of ML 80187 (near Tooloombah Creek).
WMP04	16.9	[0.6]	Continuous Datalogger installed in September 2019. Western Extent of ML 80187 (near Tooloombah Creek).
WMP08	33.4	[1.1]	Beyond Southern Extent of ML 80187 (near Deep Creek / Brussels Creek Confluence).
WMP09	26.4	-	Toward Southern Extent of ML 80187 (near Deep Creek).
WMP12	9.9	-	Occasionally Dry Bore at North-Western Extent of ML 80187.
WMP15	33.2	[1.1]	South-Western Extent of ML 80187.
WMP17	31.0	-	Beyond South-Eastern Extent of ML 80187.
WMP18	18.7	-	Eastern Extent of ML 80187 (near Barrack Creek).
WMP25	34.0	-	Wetland 1.
WMP26	12.6	-	Central North of ML 80187 (near drainage line).
WMP29B	3.3	0.5	Several Kilometres Downstream on Styx River (Upstream of Granite Creek and Montrose Creek Confluence).
BH02X	64.1	-	Landholder Bore - Brussels Creek Upper Catchment.
BH18	69.2	-	Landholder Bore - Deep Creek Upper Catchment. *[See also ID 88891]*

* Refer to **Table A4-1** (**Attachment 4**) and CDM Smith (2018e-g; 2018j) for historical datasets (including additional measurements, drill logs, bore census details). Statistical average presented based on available datasets (including additional data ending 3rd quarter 2019) provided by Orange Environmental Pty Ltd (2019). Statistical average standing water levels used in groundwater model steady state calibration (**Section 7.7**). Individual / monthly average measurements used in groundwater model transient calibration (**Section 7.7**).

\# Standard deviation calculation based on dataset refinements considering peer review feedback.

[] Measured change during groundwater sampling following bailing.

^ 2017 landholder bore survey (CDM Smith, 2018j).

~ February and May 2017.

The results of sampling of the standpipe bores for Quaternary Alluvium groundwater quality are discussed separately in **Section 5.5**. The results of the stygofauna sampling (Yeats Consulting, 2012) are also described separately in **Section 5.3.4**.

In addition to the above, 10 standpipe groundwater monitoring bores across the CQC Project area are considered screened in the Quaternary Pleistocene Alluvium / Regolith (and/or deeper Qa units), including: WMP02; WMP04; WMP08, WMP09; WMP12; WMP17; WMP18; WMP25, WMP26 and WMP29B.

Similar to the groundwater levels in Quaternary Alluvium groundwater monitoring bores, a gradual decline in standing water levels has been observed since December 2017 in line with the cumulative rainfall residual, albeit less pronounced than WMP05, BH16 and BH01X.

In general, groundwater levels in the Qpa units reflect topography from upstream to downstream of the CQC Project within the Tooloombah Creek and Deep Creek catchments (i.e. 17 mAHD near Tooloombah Creek [WMP04; WMP06] and more than 25 mAHD near Deep Creek [WMP08; WMP09], to below 10 mAHD toward the confluence of Deep Creek and Tooloombah Creek [WMP02; WMP12]). Further discussion of the spatial variability of groundwater levels is provided in **Section 5.4.1**.

Whilst the frequency of recorded groundwater levels at the WMP Series 16-30 within the Qpa / Regolith units has been less than the WMP Series 02-15, the relative consistency of groundwater levels (piezometric at depth) after initial construction by comparison is notable, regardless of the cumulative rainfall residual. Monthly baseline groundwater level has since been re-established to allow future investigation of rainfall recharge magnitude following rainfall events. As discussed above, continuous dataloggers have also been fitted to WMP05 (Qa) and WMP04 (Qpa). These alluvial groundwater bores have also been surveyed for ground level and stick-up measurements which, in addition to WMP29A, is presented in **Section 8.12.3**.

Groundwater levels in WMP29B, furthest downstream, appear to be relatively stable and generally consistent with the shallow monitoring in WMP29A reflecting the influence of the perturbing, but overall generally constant, coastal tidal head conditions (**Section 3.3.2**).

It is also noted that groundwater levels at WMP29B did not appear to have the lower recovery pressures observed in the deeper bores (WMP29C and WMP29D) during their development, and therefore does not provide any clear evidence of influence of historic mining at the Styx No.3 workings in the shallower Quaternary units (i.e. water levels recorded at approximately 3.3 mAHD and 3.4 mAHD at present).

As noted on the hydrograph in **Attachment 8**, the 1st datapoint following construction of the groundwater monitoring bore WMP05 (**Graph A8-5**) was removed from the statistical dataset as it was in recovery at the time of its development.

Targeted Groundwater Investigation Results – Aquifer Testing (AMEC, August 2019)

Additional drill hole and standpipe groundwater level monitoring was conducted as part of a targeted groundwater investigation by AMEC in the 3rd Quarter of 2019 at WMP04. Relevant minimum and maximum datasets are also presented on the hydrograph (**Graph A8-12**) in **Attachment 8** with recorded levels consistent with monthly results.

5.1.2 Drill Logs and Standpipe Bores – Styx Coal Measures (Overburden, Coal Seams, Interburden and Underburden)

In total, there are 22 standpipe groundwater monitoring bores across the CQC Project which are considered screened in the Early Cretaceous Styx Coal Measures. In addition, 36 exploration drill holes within the tenements and six landholder bores have also recorded standing water levels in the Styx Coal Measures.

Of the 22 groundwater monitoring network bores, four are specifically targeted within the Styx Interburden and Coal Seams, and three in the Styx Underburden (which is supplemented by the 36 exploration drill holes standing water level measurements).

Details of the standpipe groundwater monitoring bores at the CQC Project in the Styx Coal Measures are provided in **Table 5-3** and all available groundwater level datasets are presented graphically in **Attachment 8 (Graphs A8-21 to A8-42)** with the statistical average (based on available datasets) presented for relative comparison.

Table 5-3
Groundwater Measurement Points in Mapped Styx Coal Measures

Measurement Point	SWL (mAHD)*	Measured Change[#] Greater Than 0.5 m	Comments
Styx Coal Measures - Overburden (and Quaternary Alluvium [Lower]) / Weathered Regolith			
WMP04D [WMP04A]	16.7	[1.8]	Paired Deeper Bore at WMP04. North-Western Extent of ML 80187 (near Tooloombah Creek).
WMP10	19.6	1.2	Eastern Extent of ML 80187 (near Deep Creek and Barrack Creek confluence). Steadily declining groundwater levels in line with Cumulative Rainfall Residual for the period since 2017.
WMP13	4.2	-	North and Downstream on lower reaches of Styx River near Ogmore Road Bridge Crossing.
WMP14	15.2	-	Western Extent of ML 80187 (Tributary Sub-Catchment near Tooloombah Creek).
WMP21D	11.3	-	North-East Extent of ML 80187 (near Deep Creek).
Styx Coal Measures - Overburden / Coal Seams and Interburden			
WMP10D	-[#]	-	Drillers noted that the SWL was not recorded in the exploration drill hole (during construction) to 50.5 m depth.
WMP11[+]	5.9	[1.2]	North and Downstream at Deep Creek and Tooloombah Creek confluence. Drill hole to -5 mAHD.
WMP11D[+]	6.4	[5.0]	North and Downstream at Deep Creek and Tooloombah Creek confluence. Drill hole to -17 mAHD with sample bailing to -10 mAHD.
WMP17D	31.2	-	Up-Catchment and Beyond South-Eastern Extent of ML 80187.
WMP18D	16.3	-	Eastern Extent of ML 80187 (near Deep Creek).
WMP22A	15.0	-	West North-Western Extent of ML 80187 (near Tooloombah Creek).
WMP23A	26.0	-	Up-Catchment and within Southern Extent of ML 80187 (near Deep Creek).
WMP24	14.9	-	Western Extent of ML 80187 (near Tooloombah Creek). West of Alluvial Vine Thicket Assessment Area. Screened at approximately -4 to -7 mAHD.
WMP27	13.0	-	Western Extent of ML 80187 (Tributary Sub-Catchment near Tooloombah Creek). Wetland 2.
WMP28	11.3	-	Western Extent of ML 80187 (near Tooloombah Creek). Alluvial Vine Thicket Assessment Area. Screened at approximately 10 to 13 mAHD.
WMP29C^	-1.6	9.0	Several Kilometres Downstream on Styx River (Upstream of Granite Creek and Montrose Creek Confluence). Screened at approximately -40 to -46 mAHD.
WMP29D^	-9.1	1.6	Several Kilometres Downstream on Styx River (Upstream of Granite Creek and Montrose Creek Confluence). Screened at approximately -103 to -109 mAHD.
WMP30A	15.5	-	West North-Western Extent of ML 80187 (near Tooloombah Creek).
BH30	62.5	-	Landholder Bore - Brussels Creek Upper Catchment.

Table 5-3 (Cont.)
Groundwater Measurement Points in Mapped Styx Coal Measures

Measurement Point	SWL (mAHD)*	Measured Change[#] Greater Than 0.5 m	Comments
Styx Coal Measures - Coal Seams			
WMP22B	14.9	-	West North-Western Extent of ML 80187 (near Tooloombah Creek).
WMP30B	15.8	-	West North-Western Extent of ML 80187 (near Tooloombah Creek). Aquifer Test Conducted in October 2018.
Styx Coal Measures - Underburden (and Quaternary Alluvium [Lower]) / Weathered Regolith			
WMP06	16.9	-	Beyond Western Extent of ML 80187 (near Tooloombah Creek and Mamelon Creek Confluence). Regolith (Styx Coal Measures – Underburden).
Styx Coal Measures - Underburden			
WMP07	71.8	-	Beyond South-Western Extent of ML 80187 (rising toward Mt Mamelon).
WMP08D	33.9	-	Beyond Southern Extent of ML 80187 (near Deep Creek / Brussels Creek Confluence).
BH3 [Wetland 1]	30.7	-	Investigation Drill Hole. Wetland 1.
BH08 [91715]	116.6	-	Landholder Bore - Beyond South-Western Extent of ML 80187 (Mamelon Creek Catchment).
88890 [BH19]	64.7 [68.7][?]	-	Landholder Bore - Deep Creek Upper Catchment.

* Refer to CDM Smith (2018e-g; 2018j) for historical datasets. Statistical average presented based on available datasets (ending 3rd quarter 2019). Standing water levels used in groundwater model steady state calibration (**Section 7.7**).

^ Located near the historic mine workings at Ogmore.

[+] Located near the historic mine workings at Bowman.

[#] No water flows were encountered during drilling at depths of 12.5m, 18.5m, 24.5m, 27.5m, 30.5m, 33.5m, 36.5m, 39.5m, 42.5m, 45.5m, 48.5m and 50.5m (Mitchell Services, 26 September 2017).

[?] Measured differential reflects the reported and approximated ground levels (74 mAHD and 70.8 mAHD).

Based on the datasets collected, the following observations are made:

- The SWL in the upper stratigraphy of the Styx Coal Measures is generally recorded at approximately 15 mAHD (or less) within the CQC Project open cut extent within ML 80187.
- The SWL at WMP11 and WMP11D located north of ML 80187 and closer to the historic mine workings at Bowman in the regolith and upper stratigraphy of the Styx Coal Measures, are approximately 5-10 m lower than within ML 80187.
- WMP10, WMP17D, WMP18D and WMP23A, located to the east and south-east of ML 80187 in the Styx Coal Measures, is generally recorded at greater than approximately 15 mAHD.
- The piezometric pressure head / elevation in the lower stratigraphy of the Styx Coal Measures at WMP06 (16.9 mAHD) where it subcrops in the west, and near the pinch / saddle point downstream of the Mamelon Creek and Tooloombah Creek confluence (to the west), Mt Brunswick and Mt Mamelon, and sub-catchment tributary of Tooloombah Creek, is equivalent to the recorded groundwater levels recorded approximately 2.5 km downstream at WMP04 and WMP04D (16.9 mAHD; 16.7 mAHD). Analysis of salinity (EC) concentrations at WMP06 and downstream gauging station readings at ToGS01 are provided separately in **Section 5.5.7**.
- The piezometric pressure head / elevations in the WMP29A-E series were recorded at the screen depths as follows with potential evidence of residual depressurisation (in recovery) due to historic mine workings at Ogmore at equivalent depths of coal seams:
    - WMP29A: 6.5-12.5 mbgl (3.4 mAHD);
    - WMP29B: 16-20 mbgl (3.3 mAHD);

  - WMP29C: 52-58 mbgl (-**1.6 mAHD**);
  - WMP29D: 115-121 mbgl **(-9.1 mAHD**); and
  - WMP29E: 222.5-228.5 mbgl (5.5 mAHD).

Further observations based on the datasets collected both spatially and temporally are discussed separately in **Section 5.4**. As noted on the hydrographs in **Attachment 8**, the 1st datapoint following construction of the groundwater monitoring bore WMP08D (**Graph A8-24**) was removed from the statistical dataset as it was in recovery at the time of its development.

Groundwater Investigations for Styx Trial Pit (AMEC, 2014)

Aquifer testing was conducted in 2014 at two locations at the Styx Trial Pit (AMEC, 2014) south of the Bruce Highway in the south-east of ML 80187. Pump out testing and flow rate measurements were undertaken at two bores (STX104 and STX205), in conjunction with drawdown observation at adjacent bores (STX103, STX170 and STX204).

The recorded SWL measurements at the beginning of the aquifer testing were as follows (AMEC, 2014):

- STX103 = 9.85 mbgl;
- STX104 = 10.05 mbgl;
- STX170 = 9.85 mbgl;
- STX204 = 10.15 mbgl; and
- STX205 = 9.93 mbgl.

Based on the ground elevations (35 mAHD), the SWLs recorded in 2014 were all at approximately 25 mAHD in the south-east of ML 80187.

5.1.3 Drill Logs and Standpipe Bores – Permian Measures (Back Creek Group / Boomer Formation) and Other Volcanic Units (Lizzie Creek Volcanic Group including Carmila Beds)

In total, there are 10 standpipe groundwater monitoring bores which are considered screened at the base of the Early Cretaceous Styx Coal Measures and/or within the Permian Measures.

The western transect of groundwater monitoring bores installed in 2018 (WMP16, WMP16D, WMP19, WMP19D, WMP20, WMP20D) specifically target the stratigraphic sequence at the base of the Early Cretaceous Styx Coal Measures which are mapped and outcrop in the west (i.e. as the Back Creek Group).

WMP23B is the most southern and one of the deepest groundwater monitoring bores within ML 80187 at approximately 194 mbgl. WMP29E is the most northern beyond ML 80187 and screened at a depth of 228.5 mbgl.

Details of the standpipe groundwater monitoring bores at the CQC Project in the Permian Measures (and/or Styx Coal Measures Underburden) are provided in **Table 5-4**. All available groundwater level datasets are presented graphically in **Attachment 8 (Graphs A8-43 to A8-54)**, and the statistical average (based on available datasets) presented for relative comparison.

Notably, groundwater level measurements at WMP23B (screened at a depth greater than -150 mAHD) (**Graph A8-53**) have been recorded at, or just below, ground level, and approximately 10 m higher than the adjacent groundwater monitoring bore (WMP23A) screened in the Styx Coal Measures at approximately -15 mAHD (**Graph A8-31**).

Table 5-4
Groundwater Measurement Points in Mapped Permian Measures and Other Volcanic Units

Measurement Point	SWL (mAHD)*	Standard Deviation Greater Than 0.5 m	Comment
Permian Measures – Back Creek Group (and Styx Coal Measures - Underburden)			
WMP29E^	5.5	-	Several Kilometres Downstream on Styx River (Upstream of Granite Creek and Montrose Creek Confluence). Screen at -211 to -217 mAHD.
WMP22C	19.8	-	West North-Western Extent of ML 80187 (near Tooloombah Creek). Screen at -170 to -176 mAHD.
WMP30C	18.2	-	West North-Western Extent of ML 80187 (near Tooloombah Creek). Aquifer Test Conducted in October 2018. Screen at -170 to -176 mAHD.
Permian Measures – Back Creek Group			
WMP16	20.2	-	Beyond North / North-Western Extent of ML 80187 in Montrose Creek Catchment. Screen at 10 to 16 mAHD.
WMP16D	17.7	-	Beyond North / North-Western Extent of ML 80187 in Montrose Creek Catchment. Screen at 0 to 6 mAHD.
WMP19	28.0	-	Beyond Western Extent of ML 80187 in Mamelon Creek Catchment. Screen at 25 to 28 mAHD.
WMP19D	27.8	-	Beyond Western Extent of ML 80187 in Mamelon Creek Catchment. Screen at 13 to 16 mAHD.
WMP20	23.8	-	Beyond North-Western Extent of ML 80187 and North-West of Mt Brunswick (tributary sub-catchment of Styx River). Screen at 22 to 28 mAHD.
WMP20D	23.9	-	Beyond North-Western Extent of ML 80187 and North-West of Mt Brunswick (tributary sub-catchment of Styx River). Screen at 13 to 19 mAHD.
Permian Measures – Carmila Beds (and/or Back Creek Group)			
WMP23B	36.9	-	Up-Catchment and within Southern Extent of ML 80187 (near Deep Creek). Screen at -151 to -157 mAHD.

* Refer to CDM Smith (2018e-g; 2018j) for historical datasets. Statistical average presented based on available datasets (ending 3rd quarter 2019). Standing water levels used in groundwater model steady state calibration (**Section 7.7**).

^ Located near the historic mine workings at Ogmore.

As discussed in **Section 5.4**, a new VWP was installed in December 2019 targeting the basement aquifers in a north-east/east drill hole (WMP31) in the Permian Measures east of the fault. Details of the new VWP installation is provided in **Table 5-5**.

Table 5-5
Vibrating Wire Piezometer (WMP31) Installation Details and Initial Measurements

Measurement Point		SWL (mAHD)*	Comment
Permian Measures – Back Creek Group			
WMP31	50 mbgl	35.0	Piezo No. s3048 – Wire depth at approximately -3 mAHD.
	94 mbgl	34.0	Piezo No. s2893 – Wire depth at approximately -47 mAHD.
	103.5 mbgl	33.8	Piezo No. s3025 – Wire depth at approximately -83.5 mAHD.
	171 mbgl	33.4	Piezo No. s3026 – Wire depth at approximately -124 mAHD.

Source: GES (2020)

*Last measurement taken on 18 February 2020 (in recovery since installation) (refer to **Attachment 8**), based on an approximate RL of 47 mAHD at Walton Bore Geophysics drill hole coordinate 778070 E 7489063 N.

The initial datasets available (**Attachment 8; Graph A8-54**) show that groundwater levels/pressures have been recovering since installation to approximately 33-35 mAHD in February 2020.

Government Database Searches - Landholder Bores

As discussed separately in **Sections 5.2.2** and **5.2.3**, historic records of SWL in landholder bores drilled in the Permian Measures (Back Creek Group / Boomer Formation) and Other Volcanic Units (Lizzie Creek Volcanic Group including Carmila Beds) have been utilised where available.

5.1.4 Drill Logs and Standpipe Bores – Wetlands 1 & 2 and Alluvial Vine Thicket Assessment Area (Tooloombah Creek)

Six shallow drill holes were installed at the CQC Project as a component of the targeted GDE investigations by CDM Smith (2018g) and presented in Section 5 of Appendix 6 in the SEIS. A summary of the groundwater level measurements at the Wetlands and Alluvial Vine Thicket Assessment Area is presented in **Table 5-6**. Further details of the targeted GDE investigations are provided in **Section 5.3.2**.

Table 5-6
Groundwater Measurement Points at Potential GDEs

Measurement Point	SWL (mAHD)*	Measured Change[#] If Greater Than 0.5 m	Comments
Wetland 1			
BH1	**[Dry]**	-	Drilled depth to 4.2 m.
BH2	**[Dry]**	-	Drilled depth to 4.0 m.
BH3	30.7	-	Drilled depth to 14.5 m. **Depth to groundwater approximately 13.5 m^**.
WMP25	34.0	-	Drilled depth 13.2 m. Screened at 31 to 34 mAHD. **Depth to groundwater approximately 10.2 m**.
Wetland 2			
BH4	**[Dry]**	-	Drilled depth to 4.2 m.
BH5	**[Dry]**	-	Drilled depth to 15 m.
WMP27	13.0	-	Drilled depth to 20.5 m. Screened at 12.5 to 18.5 mAHD. **Depth to groundwater approximately 20 m**.
Alluvial Vine Thicket Assessment Area			
BH6	**[Dry]**	-	Drilled depth to 9.9 m.
WMP28	11.3	-	Drilled depth to 21.9 m. Screened at approximately 10 to 13 mAHD. **Depth to groundwater approximately 10.6 m**.

* Refer to CDM Smith (2018e-g; 2018j) for historical datasets. Statistical average presented based on available datasets (ending 3rd quarter 2019). Standing water levels used in groundwater model steady state calibration (**Section 7.7**).
^When constructed. Subsequently backfilled.

5.2 ANTHROPOGENIC GROUNDWATER USAGE

5.2.1 ML 80187 and ML 700022

Exploration drilling and aquifer testing has occurred extensively within the CQC Project tenements. The exploration drilling program undertaken at the CQC Project tenements and surrounds is described in **Section 3.4.5**. An overview of the aquifer testing programs including rising head (i.e. pumping tests) conducted since 2011 is also provided in **Section 5.6**.

Groundwater quality sampling occurs at the CQC Project groundwater monitoring network within the CQC Project tenements and surrounds. Bailing of groundwater monitoring bore columns is undertaken periodically in accordance with relevant water quality sampling requirements to obtain representative samples.

A windmill (WP001) and tank (Ring Tank) is also on file (CQCPL, 2020) as being next to a turkey's nest dam at the Mamelon Station. Beside this is also an historic record of groundwater bore Mm1. No other data / use information is available besides water quality measurements from the nearby turkey's nest dam which the Ring Tank overflows to presented in **Section 3.2.7**.

5.2.2 Government Database Searches

A comprehensive search of the Qld Government Groundwater Database (Qld Globe) was conducted and presented in CDM Smith (2018f). A census of third party groundwater bores was also completed in 2017 and the results presented in CDM Smith (2018j).

A contemporary search of the Qld Government Groundwater Database (Qld Globe) and Australian Groundwater Explorer (BOM) Database was conducted in November 2019 for the purposes of correlating with registered numbers associated with previous groundwater data reported at the CQC Project and surrounds, and to identify any new groundwater monitoring bores constructed. The database search results are presented in **Table 5-7**, with reference to specific details in relevant sub-sections of **Section 5.1**, and where possible correlation and aggregation of relevant data sets. For ease of reference, search results are presented spatially (north-south-east-west) with reference to the CQC Project.

5.2.3 Landholder Bores

Based on a review of the Government database searches, and bore census results, a concise list of landholder use bores is provided in **Attachment 4 (Table A4-2).** Further details are also available in CDM Smith (2018e).

Landholder Bore Survey (2017)

A landholder bore survey was completed in 2017 by CDM Smith (2018e) and targeted landholder groundwater bores accessible within approximately 10 km of the CQC Project. Following an updated review of the Government database searches, a record of a new bore (187278) installed approximately 10 km downstream near the Styx River in August 2019 was identified and has been considered in **Section 8.7.1**.

It is also noted that BH20 is a landholder bore in use with two groundwater monitoring locations nearby (BH01X and BH16) (**Attachment 8; Graph A8-7 and Graph A8-8**). There does not appear to be any distinct response in groundwater levels at these bores as a result of landholder pumping of groundwater from BH20, however as described in **Section 5.1.1**, some localised groundwater drawdown and corresponding fluctuations in groundwater levels at the locations (BH01X and BH16) could be as a result of an existing landholder groundwater bore in use at BH20 for stock watering.

5.3 ENVIRONMENTAL GROUNDWATER USAGE

5.3.1 Springs

No groundwater springs were identified at the CQC Project by CDM Smith (2018e). Nevertheless GDEs are assessed separately by Eco Logical Australia Pty Ltd (2020a), where there is a higher potential for near surface expression.

Table 5-7
Qld Government Groundwater Database / BOM Australian Groundwater Explorer Database Search Results

Database / Bore ID	Lat.	Long.	Date Drilled	Bore Depth	Inferred Geology	Other
North – Granite Creek Catchment [New Hope Drilling Program]						
91746 [*New Hope 9013*]	-22.590	149.606	Nov 1993	17.0 m	Quaternary Alluvium [*Log = Gravel*]	Abandoned and Destroyed
91748 [*New Hope 9014*]	-22.587	149.616	Nov 1993	96.5 m	Quaternary Alluvium & Styx Coal Measures [*Log = Gravel & Coal*]	Abandoned and Destroyed
91749 [*New Hope 9015*]	-22.587	149.619	Nov 1993	83.5 m	Quaternary Alluvium & Styx Coal Measures [*Log = Gravel & Coal*]	Abandoned and Destroyed
91750 [*New Hope 9016*]	-22.586	149.622	Nov 1993	92.8 m	Quaternary Alluvium & Styx Coal Measures [*Log = Gravel & Coal*]	Abandoned and Destroyed
91751 [*New Hope 9017*]	-22.577	149.615	Nov 1993	83.5 m	Quaternary Alluvium & Styx Coal Measures [*Log = Gravel & Coal Lens*]	Abandoned and Destroyed
91752 [*New Hope 9018*]	-22.576	149.618	Nov 1993	59.5 m	Quaternary Alluvium & Styx Coal Measures [*Log = Gravel & Shaly Coal*]	Abandoned and Destroyed
91753 [*New Hope 9019*]	-22.556	149.617	Nov 1993	125.5 m	Quaternary Alluvium & Styx Coal Measures [*Log = Gravel & Coal*]	Abandoned and Destroyed
North-West – Granite Creek Catchment						
91457 [*Shannon No.3 OLO*]	-22.621	149.510	Jun 1965	20.4 m	Lizzie Creek Volcanic Group / Carmila Beds [*Log = Blue Diorite*]	EC = 1,400 µS/cm & Water Quality
North-West – Montrose Creek Catchment						
91456 [*Shannon No.2 OLO*]	-22.652	149.469	Jun 1965	16.8 m	Lizzie Creek Volcanic Group / Carmila Beds [*Log = Blue-Green Serpentinite Granite*]	EC = 1,800 µS/cm
West – Sarsfield Creek / Mamelon Creek / Tributary of Tooloombah Creek Catchment						
88146 [*BH23*]	-22.714	149.580	Jun 1965	27.4 m	Mamelon Creek Alluvium / Styx Coal Measures	SWL = 11.8 m EC = 1,000 µS/cm Pump Test (at 20.8 m) & Water Quality
91455 [*Shannon No.1 OLO*]	-22.699	149.468	Jun 1965	24.2 m	Lizzie Creek Volcanic Group / Carmila Beds [*Green-Red Serpentinite Granite*]	EC = 3,800 µS/cm
97654 [*Montrose Grazing Co*]	-22.688	149.500	Nov 1997	24.0 m	Intermediate Volcanic / Carmila Beds [*Log = Andesite*]	EC = 2,200 µS/cm
97864 [*McCartney / BH28*]	-22.716	149.634	Jun 1998	55.0 m	Back Creek Group [*Boomer Formation*]	SWL = 12 mbgl EC = 900 µS/cm
South-West – Tooloombah Creek South Branch Catchment						
122994	-22.826	149.438	Oct 2004	41.0 m	Volcanic [*Log = Andesite*]	SWL = 25 mbgl EC = 488 µS/cm
161437	-22.829	149.446	Feb 2016	42.0 m	Volcanic	Dry Hole
161438	-22.814	149.440	Feb 2016	42.0 m	Volcanic [*Log = Granite*]	Abandoned and Destroyed
97827 [*White – Bullock Pad #2*]	-22.813	149.496	Jan 1994	30.0 m	Carmila Beds / Lizzie Creek Volcanic Group	EC = 890 µS/cm

Table 5-7 (Continued)
Qld Government Groundwater Database / BOM Australian Groundwater Explorer Database Search Results

Database / Bore ID	Lat.	Long.	Date Drilled	Bore Depth	Inferred Geology	Other
South-West – Tooloombah Creek South Branch Catchment (Cont.)						
97830 [*White*]	-22.814	149.501	Apr 1998	19.0 m	Carmila Beds / Lizzie Creek Volcanic Group	SWL = 10 mbgl EC = 2,700 µS/cm
South-West – Magdalen Creek Catchment						
161478	-22.800	149.501	Jun 2016	30.0 m	Lizzie Creek Volcanic / Carmila Beds	SWL = 10 mbgl Pump Test (at 25 m)
South-West – Kyour Creek Catchment						
97825 [*White – Scrub Dam Bore*]	-22.794	149.536	Oct 1997	24.0 m	Connors Volcanic [*Log = Acid Intrusive, Granite*]	SWL = 9 mbgl EC = 3,000 µS/cm
97826 [*White – Old Mill Bore*]	-22.782	149.543	Oct 1997	18.0 m	Connors Volcanic [*Log = Basalt*]	EC = 4,200 µS/cm
97829 [*White – House Bore / BH17*]	-22.748	149.559	Feb 1990	24.5 m	Lizzie Creek Volcanic / Carmila Beds [*Log = Serpentinite*]	SWL = 3 mbgl
161292 [*Hill Paddock Bore*]	-22.754	149.551	Jul 2015	30.0 m	Lizzie Creek Volcanic / Carmila Beds [*Log = Andesite*]	SWL = 15 mbgl EC = 2,700 µS/cm & Pumping Test (at 22 m)
161946	-22.763	149.550	Nov 2018	30.0 m	[*Log = Serpentinite, Fresh*]	Abandoned and Destroyed
187293^{+}	-22.809	149.564	Sep 2019	37.0 m	[*Log = Siltstone*]	Abandoned and Destroyed
187294^{+}	-22.808	149.564	Sep 2019	49.8 m	[*Log = Siltstone*]	Abandoned and Destroyed
12700003	-22.772	149.562	Aug 2009	172.0 m	Quaternary (3 m) & Carmila Beds [*Log = Tuff 3-45 m*]	Minor Water at 51 mbgl and 106 mbgl
South-West – Oaky Creek Catchment						
97828 [*White – Langdale Bore*]	-22.829	149.547	Feb 1990	26.0 m	Connors Volcanic Group [*Log = Serpentinite*]	SWL = 5 mbgl
187295^{+}	-22.836	149.560	Sep 2019	27.0 m	Carmila Beds [*Log = Andesite*]	SWL = 12 mbgl EC = 3,500 µS/cm Pumping Test (at 24 m)
South-West – Mamelon Creek Catchment						
88145 [*BH22*]	-22.755	149.597	Jun 1965	18.3 m	[*Log = Siltstone*]	SWL = 6.37 mbgl EC = 2,850 µS/cm Pumping Test (at 11.7 m) & Water Quality Abandoned and Destroyed
91715 [*McCartney / BH08*]	-22.744	149.625	Sep 1994	47.0 m	Styx Coal Measures [*Log = Siltstone*]	SWL = 25 mbgl
97562 [*FG Shannon / BH07*]	-22.806	149.598	Oct 1997	30.4 m	Volcanic / Back Creek Group Undifferentiated [*Log = Weathered Siltstone*]	SWL = 13.7 mbgl EC = 4,100 µS/cm
97866 [*Shannon / BH06*]	-22.801	149.614	Jun 1998	25.0 m		SWL = 13.0 mbgl EC = 3,000 µS/cm
South – Brussels Creek Catchment						
88144 [*Shannon / BH21*]	-22.801	149.622	Jun 1965	16.2 m	Styx Coal Measures [*Log = Weathered Shale*]	SWL = 9.8 mbgl EC = 4,500 µS/cm
161945^{+}	-22.827	149.614	Nov 2018	25.0 m	Back Creek Group [*Boomer Formation*] [*Log = Siltstone*]	SWL = 16.0 mbgl EC = 3,500 µS/cm

Table 5-7 (Continued)
Qld Government Groundwater Database / BOM Australian Groundwater Explorer Database Search Results

Database / Bore ID	Lat.	Long.	Date Drilled	Bore Depth	Inferred Geology	Other
South – Deep Creek						
88889 [*ABD Bore 1 OLO*]	-22.795	149.711	Nov 1965	13.7 m	No Data [*See 88891*]	SWL = 4.7 mbgl EC = 7,750-7,810 µS/cm & Water Quality
88890 [*New Bore 2 OLO*]	-22.817	149.659	Jul 1980	19.2 m	Styx Coal Measures [*Log = Carbonaceous Slate*]	SWL = 6.1 mbgl EC = 4,800 µS/cm
88891 [*Replaced ABD Bore 1*]	-22.796	149.708	Aug 1980	25.3 m	Tertiary Sediments [*Log = Cemented Gravel*]	SWL = 4 mbgl EC = 9,260-9,680 µS/cm & Water Quality
88892 [*Bore 4*]	-22.853	149.670	Jan 1900	25.0 m	Back Creek Group [*Boomer Formation*]	EC = 1,200 µS/cm
91191 [*Richardson / BH35 / Neerim 4*]	-22.847	149.673	Dec 1993	19.5 m	Styx Coal Measures [*Log = Fractured Siltstone*]	SWL = 2.2 mbgl EC = 6,400-7,240 µS/cm & Water Quality
161293 [*White Cow Paddock Bore*]	-22.853	149.627	Jul 2015	35.0 m	Back Creek Group [*Log = Slate*]	SWL = 3.0 mbgl EC = 1,700 µS/cm & Pumping Test (at 9 m)
North – Tooloombah Creek and Styx River						
57794 [*BH20*]	-22.633	149.664	Nov 1979	9.8 m	Quaternary Alluvium [*Log = Gravel*]	SWL = 5.0-8.5 mbgl EC = 420 µS/cm & Pumping Test & Water Quality (1980)
67652 [*BH16*]	-22.634	149.662	Feb 1990	9.5 m	Quaternary Alluvium [*Log = Gravel & Sand*]	SWL = 2.6 mbgl EC = 712 µS/cm
67653 [*BH26*]	-22.561	149.640	Feb 1990	8.0 m	Quaternary Alluvium [*Log = Sand*]	SWL = 3.0 mbgl EC = 6,490-13,090 µS/cm & Water Quality (1993)
67654 [*Olive AM OLO / BH25*]	-22.524	149.663	Mar 1990	7.0 m	Quaternary Alluvium [*Log = Gravel & Sand*]	SWL = 3.0 mbgl EC = 11,620-40,600 µS/cm & Water Quality (1992-2002)
67656 [*Soppa OLO / BH37 {Riverside 1}*]	-22.591	149.631	Mar 1990	10.0 m	Quaternary Alluvium [*Log = River Gravel*]	SWL = 7.0 mbgl
84983 [*Well No.1 / BH24*]	-22.644	149.657	Jan 1960	2.6 m	Quaternary Alluvium [*Log = Sand*]	SWL = 1.74 mbgl EC = 1,555 µS/cm Pumping Test & Water Quality (1971)
91567 [*Soppa / BH06X*]	-22.595	149.634	Sep 1990	8.8 m	Quaternary Alluvium [*Log = Sand & Gravel*]	SWL = 3 mbgl
111417 [*Soppa / BH05X / Riverside 2*]	-22.589	149.635	Apr 2000	11.0 m	Quaternary Alluvium [*Log = Gravel*]	EC = 10,000 µS/cm
111418 [*Soppa / BH04*]	-22.616	149.649	Apr 2000	11.9 m	Quaternary Alluvium [*Log = Gravel*]	EC = 9,500 µS/cm
187278^{+} [*New Bore*]	-22.598	149.642	Aug 2019	21.0 m	Quaternary Alluvium [*Log = Sand & Gravel*]	SWL = 12.0 mbgl EC = 15,000 µS/cm & Pumping Test

Table 5-7 (Continued)
Qld Government Groundwater Database / BOM Australian Groundwater Explorer Database Search Results

Database / Bore ID	Lat.	Long.	Date Drilled	Bore Depth	Inferred Geology	Other
North-East – Wellington Creek and Tributary to Styx River Mouth						
91884 [*Galea OLO*]	-22.511	149.781	Mar 1990	24.0 m	Granite	SWL = 12 mbgl
97641 [*P97 - Galea S*]	-22.545	149.751	Jan 1993	12.2 m	-	EC = 7,500 µS/cm
111480 [*Beresford*]	-22.462	149.805	Apr 2000	21.3 m	Lizzie Creek Volcanic Group – Carmila Beds [*Log = Andesite*]	SWL = 4.6 mbgl EC = 4,100 µS/cm
111559 [*Vella*]	-22.484	149.800	Oct 2001	21.3 m	Lizzie Creek Volcanic Group – Carmila Beds [*Log = Granite*]	SWL = 3.96 mbgl EC = 8,480 µS/cm
111560 [Vella]	-22.485	149.816	Oct 2001	30.5 m	Lizzie Creek Volcanic Group – Carmila Beds [*Log = Andesite*]	SWL = 10.1 mbgl EC = 4,800 µS/cm
111565 [*Vella*]	-22.449	149.822	Oct 2001	18.3 m	Carmila Beds [*Log = Andesite*]	SWL = 9.14 mbgl EC= 8,040 µS/cm
111566 [*Vella*]	-22.474	149.798	Oct 2001	6.1 m	Quaternary Alluvium [*Log = Gravel*]	SWL = 2.74 mbgl EC = 6,000 µS/cm
111593 [*Galea*]	-22.567	149.767	Oct 2001	18.3 m	Volcanic – Carmila Beds [*Log = Andesite*]	SWL = 11 mbgl EC= 3,500 µS/cm
122987	-22.470	149.814	Oct 2004	36.0 m	Carmila Beds [*Log = Basalt*]	SWL = 22 mbgl EC = 3,500 µS/cm
122989	-22.486	149.819	Oct 2004	24.0 m	Lizzie Creek Volcanic Group – Carmila Beds	SWL = 10 mbgl EC = 3,600 µS/cm
136065	-22.469	149.804	Oct 2004	16.0 m	Carmila Beds [*Log = Basalt*]	SWL = 10 mbgl EC = 7,200 µS/cm Abandoned and Destroyed
151113	-22.569	149.712	Sep 2009	42.0 m	[*Log = Shale*]	Abandoned and Destroyed
151948 [*Tanderra Scrub*]	-22.499	149.788	Oct 2013	30.0 m	Granite	SWL = 10 mbgl EC = 860 µS/cm
161189	-22.516	149.803	Oct 2014	60.0 m	Volcanics [*Log = Serpentinite*]	SWL = 25 mbgl EC = 5,800 µS/cm
161351	-22.512	149.770	Oct 2015	60.0 m	Glenprairie Beds [*Log = Andesite & Sandstone*]	SWL = 43 mbgl
161355	-22.517	149.782	Oct 2015	60.0 m	Glenprairie Beds [*Log = Andesite & Siltstone*]	Abandoned and Destroyed
East – Ewan Creek, Oaky Creek and Wellington Creek						
67650	-22.650	149.839	Feb 1990	20.5 m	Carmila Beds [*Log = Hard Siltstone*]	SWL = 4 mbgl
91572 [*Rackerman OLO / BH13*]	-22.715	149.768	Oct 1992	29.0 m	Back Creek Group / Boomer Formation [*Log = Siltstone*]	SWL = 12 mbgl EC = 1,700 µS/cm
111311	-22.692	149.789	Jan 1900	12.5 m	Boomer Formation [*Log = Sandstone*]	EC = 16,100 µS/cm & Water Quality
111312 [*Hals Bore*]	-22.712	149.826	Jan 1967	19.2 m	Carmila Beds	EC = 5,450 µS/cm & Water Quality
111428 [*Bowman*]	-22.712	149.793	Mar 2000	17.1 m	Carmila Beds [*Log = Shale*]	SWL = 9.1 mbgl EC = 1,400 µS/cm
111429 [*Bowman*]	-22.714	149.827	Mar 2000	27.4 m	Carmila Beds [*Log = Granite*]	SWL = 13.7 mbgl EC = 3,600 µS/cm
111543 [*Bowman*]	-22.692	149.834	Aug 2001	30.5 m	Carmila Beds [*Log = Andesite*]	SWL = 19.8 mbgl EC = 5,000 µS/cm
111568 [*Ferris*]	-22.739	149.801	Oct 2001	24.4 m	Carmila Beds [*Log = Shale*]	SWL = 10.1 mbgl EC = 1,100 µS/cm

Table 5-7 (Continued)
Qld Government Groundwater Database / BOM Australian Groundwater Explorer Database Search Results

Database / Bore ID	Lat.	Long.	Date Drilled	Bore Depth	Inferred Geology	Other
East – Ewan Creek, Oaky Creek and Wellington Creek (Cont.)						
136307	-22.741	149.838	Aug 2003	40.0 m	Back Creek Group Undifferentiated [Log = Shale]	SWL = 12 mbgl EC = 2,600 µS/cm
136562	-22.712	149.828	Jun 2007	27.0 m	Lizzie Creek Volcanic Group / Carmila Beds [*Log = Quartz Granite*]	SWL = 10.5 mbgl
161612	-22.685	149.808	Apr 2017	19.0 m	[*Log = Hard Siltstone*]	SWL = 8 mbgl EC = 5,800 µS/cm & Pumping Test
North-East – Landsborough Creek						
67651 [*P179*]	-22.617	149.840	Feb 1990	40.0 m	Carmila Beds [*Log = Blue Metal Rock*]	SWL = 16 mbgl
122160 [*Alice Springs Pastoral*]	-22.614	149.828	Oct 2004	30.0 m	Volcanic Carmila Beds [*Log = Fractured Shale*]	SWL = 15.2 mbgl EC = 5,500 µS/cm
122161 [*Alice Springs Pastoral*]	-22.590	149.824	Oct 2004	30.0 m	Carmila Beds [*Log = Diorite*]	Abandoned and Destroyed
122164 [*Platanus*]	-22.588	149.827	Oct 2004	48.7 m	Carmila Beds [*Log = Diorite*]	Abandoned and Destroyed
North-East – Wangrabry Creek and Stotts Creek						
97381 [*Galea*]	-22.592	149.756	Oct 1994	19.0 m	Carmila Beds [*Log = Granite*]	SWL = 4.5 mbgl EC = 4,700 µS/cm
136063	-22.574	149.778	Oct 2004	21.0 m	[*Log = Diorite*]	Abandoned and Destroyed
151938	-22.590	149.799	Apr 2013	36.0 m	[*Log = Andesite*]	Dry
151942	-22.593	149.794	Sep 2013	42.0 m	Volcanics - Youlambie Conglomerate [*Log = Andesite*]	SWL = 30.0 mbgl EC = 3,600 µS/cm & Pumping Test
151949 [*Wellington Bore*]	-22.589	149.797	Oct 2013	36.0 m	[*Log = Granite*]	SWL = 14.0 mbgl EC = 860 µS/cm
161224	-22.540	149.806	Oct 2014	24.0 m	Volcanics [*Log = Serpentinite*]	SWL = 3.0 mbgl EC = 2,350 µS/cm

Source: After Qld Government Groundwater Information Bore Reports.

$^{+}$ *New database record.*

NB: Database search results for constructed standpipe bores included as part of the groundwater monitoring network at the CQC Project are not repeated (i.e. WMP02 = 161686; WMP04 = 161691; WMP04D / WMP04A = 161685; WMP05 = 161687; WMP06 = 187085; WMP07 = 161694; WMP08 = 161700; WMP08D = 161698; WMP09 = 161693; WMP10 = 161692; WMP11 = 161763; WMP11D = 161762; WMP12 = 187086; WMP13 = 161730; WMP14 = 161764; WMP15 = 161765; WMP17 = 161902; WMP17D = 161903; WMP18 = 187039; WMP18D = 187038; WMP19 = 187029; WMP19D = 187030; WMP21 = 187035; WMP21D = 187034; WMP22A = 187053; WMP22B = 187052; WMP22C = 187051; WMP23A = 187050; WMP23B = 187049; WMP24 = 187037; WMP25 = 187031; WMP26 = 187033; WMP27 = 187032; WMP28 = 187036; WMP29A = 187061; WMP29B = 187060; WMP29C = 187059; WMP29D = 187058; WMP29E = 187057; WMP30A = 187054; WMP30B = 187055; WMP30C = 187056).

5.3.2 Wetlands and Groundwater Dependent Ecosystems (GDEs)

Wetlands 1 & 2

Wetland 1 is listed as a Great Barrier Reef High Ecological Significance (HES) Wetland Protection Area (WPA). Wetland 2 is identified as a wetland of general ecological significance (GES). CDM Smith (2018g) included targeted potential GDE investigations at both Wetlands 1 & 2, with attributes recorded as provided in **Table 5-8**. Results of the drilling program completed are provided in **Section 5.1.4**. The isotopic composition of waters associated with the wetlands and potential GDEs are also summarised in **Section 5.5.8**.

Table 5-8
Wetlands and Potential GDEs

Feature	GBR HES WPA	BOM GDE Atlas	Substrate	Vegetation
Wetland 1	Yes	Yes – artificial/highly modified wetland reliant on surface expression of groundwater.*	Clay pan. Soils are heavy clays to a depth of 1.5 m.	Predominantly broad leaf tea tree (*Melaleuca viridiflora*). A single red gum (*Eucalyptus tereticornis*) is located in the centre of the wetland.
Wetland 2	No	Yes – coastal/sub-coastal floodplain swamp reliant on surface expression of groundwater.	-	Sedges and fringed by larger red gums (*E. tereticornis*).
Alluvial Vine Thicket	No	No	Relatively sandy soils.	Community of low canopy (7–10 m) trees comprising a variety of species with occasional emergent red gums (*E. tereticornis*). Varied understory with abundant vines.

Source: After CDM Smith (2018g).
GBR HES WPA – Great Barrier Reef High Ecological Significance Wetland Protection Area.
* As demonstrated by the three shallow drill holes (BH1 to BH3) and groundwater monitoring standpipe (WMP25), the depth to groundwater is approximately 10.2 m (**Table 5-6**). The available isotope data near the surface in the soil moisture profile also indicated that vegetation at Wetland 1 was sourcing most water from the near surface (**Section 5.5.8**).

In addition to inspection observations, drilling program, groundwater level monitoring and isotope sampling of waters, leaf water potential (LWP) measurements were taken on leaves collected from trees in close proximity to the drill holes at each feature for assessment, the results of which are described in detail in CDM Smith (2018g).

The depth to groundwater at WMP25 (Wetland 1) and WMP 27 (Wetland 2) is recorded at greater than 10 m and 20 m, respectively (**Table 5-6**). CDM Smith (2018g) relevantly note that there was no indication of groundwater use at Wetland 2. A conceptual cross-section at Wetland 1 and Wetland 2 are presented in **Section 6.3.3**.

Alluvial Vine Thicket Assessment Area - Tooloombah Creek

The depth to groundwater at WMP28 (Alluvial Vine Thicket Assessment Area) is recorded at greater than 10 m. CDM Smith (2018g) relevantly note that there was no indication of groundwater use at the Alluvial Vine Thicket Assessment Area.

Tooloombah Creek

The Tooloombah Creek gauging station datasets (i.e. streamflow and water quality) are presented in **Section 3.2.7, 3.3.3 and 5.5.7** and groundwater connectivity discussed in **Section 7.7.6**. Detailed localised survey of the associated pools and rock bars by Central Queensland Coal Pty Ltd (2020) (discussed in **Section 8.12.3**) are considered separately by WRM Water & Environment Pty Ltd (2020). Refined assessment of Tooloombah Creek has been undertaken and reported separately by Eco Logical Australia Pty Ltd (2020a) and the outcomes considered as a component of the Groundwater Dependent Ecosystem Management and Monitoring Plan (**Section 10.5**).

For the purposes of understanding groundwater levels and gradients spatially upstream along Tooloombah Creek, relative to surface water flow directions, it is relevantly noted that whilst the recorded SWL at WMP06 is at approximately 17 mbgl, the absolute elevation is at 16.9 mAHD which is equivalent to the recorded groundwater levels at approximately 2.5 km downstream at WMP04 (at approximately 11.4 mbgl).

In contrast, WMP24 in the vicinity of Tooloombah Creek between these two groundwater monitoring locations has recorded SWLs at approximately 4.5 mbgl, however is screened at -4 to -7 mAHD in the deeper Styx Coal Measures[22].

Deep Creek

The Deep Creek gauging station datasets (i.e. streamflow and water quality) are presented in **Sections 3.2.7, 3.3.4 and 5.5.7** and groundwater connectivity discussed in **Section 7.7.6**.

Detailed localised survey of the associated pool control points by Central Queensland Coal Pty Ltd (2020) (discussed in **Section 8.12.3**) are considered separately by WRM Water & Environment Pty Ltd (2020). As observed during the site inspection in October 2019 (**Section 3.3.4**), the waterhole / pools monitored at Deep Creek 1 and Deep Creek 2 were dry. CDM Smith (2018e) relevantly note that in February 2017 the pools were likely to be supported by a shallow water table at that time.

Refined assessment of Deep Creek has been undertaken and reported separately by Eco Logical Australia Pty Ltd (2020a) and the outcomes considered as a component of the Groundwater Dependent Ecosystem Management and Monitoring Plan (**Section 10.5**).

5.3.3 Broad Sound Declared Fish Habitat Area (FHA-047)

The Broad Sound Fish Habitat Area (Plan FHA-047) includes terrestrial (e.g. rocky headlands, sand bars and estuarine vegetation) and aquatic (e.g. fisheries) habitats.

The groundwater table at extent of the Broad Sound Fish Habitat Area (Plan FHA-047) is expected to be largely defined by the coastal tide elevation, however as discussed in **Section 4.6.1**, it is important to note that there is a topographic low at the confluence of Granite Creek, Montrose Creek and the Styx River, immediately upstream of the Broad Sound Fish Habitat Area (Plan FHA-047) which results in a lower water table elevation (**Figure 4-10**).

5.3.4 Stygofauna

The results of the stygofauna survey conducted in 2011 and 2012 at the CQC Project is presented in detail in Appendix 9f of the SEIS (Yeats Consulting, 2012), and relevant outcomes summarised below.

Stygofauna sampling was conducted in November 2011 and March 2012, in accordance with the relevant stygofauna sampling guidelines (EPA, 2003; 2007) across 30 groundwater sampling locations at the CQC Project area and in the broader Styx Basin (**Table 5-9**).

In-situ groundwater quality measurements were taken at the time of sampling and are discussed separately in **Section 5.5**.

Of the sampling sites which recorded the presence of subterranean fauna classed as stygofauna (i.e. Habitus = Phreatobite or Stygobite), only Exploration Hole STX093 (near Deep Creek) was in the vicinity of the CQC Project, and reported the presence of water mites, but the Order (Astigmata) remained in question (Yeats Consulting, 2012). One of the groundwater fauna recorded at STX093 was also not a stygofauna animal (i.e. edaphobite).

Notably all the ‘Riverside’ sampling locations which recorded stygofauna were located toward the Styx River mouth, downstream of the CQC Project.

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[22] As described in **Section 8.12.1**, there is the opportunity for validation and comparison of future groundwater level responses (or lack thereof) and water quality changes at WMP06 following flood events, recognising the recent installation of the deeper screened WMP06D in the interburden of the Styx Coal Measures, and datalogger in WMP06 by CQCPL.

Table 5-9
Stygofauna Sampling Results – Styx River Catchment Only

Sampling Point	Sample Date		No. of Groundwater Fauna Recorded	In-situ Groundwater Quality		
	Nov 2011	Mar 12		pH	EC (µS/cm)	DO (% Saturation)
STX081		✓	Nil	6.95-7.29	17,184-24,502	16.2-23.7
STX090	✓	✓	Nil	7.87-8.61	4,223-6,458	13.5-18.0
STX091	✓	✓	Nil	7.90-8.46	1,105-1,556	15.3-32.2
STX093	✓	✓	1[A], **5[B]**	7.13-7.54	11,881-17,579	7.3-13.5
STX096	✓	✓	Nil	7.76-8.18	2,511-3,706	8.8-11.7
STX097	✓		Nil	8.38	2,471	21.5
STX105	✓		Nil	9.77	1,891	58.4
STX109			-	8.90	3,288	23.2
STX112	✓	✓	Nil	7.75-8.46	497-2,046	31.8-54.8
STX130	✓		Nil	8.97	2,964	20.6
STX135C			-	9.56	2,159	18.5
STX136C	✓		Nil	8.08	6,244	17.5
STX137			-	7.84	27,434	19.8
Neerim 1 [BH29]	✓		Nil	8.04	679	23.4
Neerim 2 [BH30]	✓		Nil	7.73	377	43.4
Neerim 3 [BH32]	✓		Nil	8.05	2,646	15.0
Riverside Well [Well01]	✓	✓	**1[C]**	7.25-7.80	4,565-4,727	20.6-35.7
Riverside 1 [BH37]	✓	✓	**1[D], 1[E]**	7.25-7.45	925-1,052	17.0-31.0
Riverside 2 [BH05X]	✓	✓	Nil	7.17-7.29	14,431-16,678	11.3-25.6
Riverside 3 [BH36]	✓	✓	**4[F]**	7.03-7.35	4,509-4,759	41.2-41.7
STX038		✓	Nil	7.84	5,405	11.2
STX077		✓	Nil	6.89	4,289	23.0
STX095		✓	Nil	6.97	2,044	14.3
STX100		✓	Nil	8.10	2,908	28.4
STX113		✓	Nil	7.68	2,218	16.3
STX114		✓	Nil	8.76	586	14.9
STX126B		✓	Nil	7.09	8,005	21.3
STX127		✓	Nil	7.67	3,274	13.2

Source: After Yeats Consulting (2012).

NB: Stygofauna sampling locations beyond the Styx River Catchment (i.e. STX020C, STX021, Granite Vale and Plainvue 1) are not tabulated.

A – Class: Entognatha; Order: Collembolla; Family: Entomodryidae; Genus/Species: Not Determined; Habitus: Edaphobite.

B – Class: Acariformes; Order: Astigmata(?); Family: Not Determined; Genus/Species: Not Determined; **Habitus: Stygobite.**

C – Class: Annelida; Order: Tubificida; Family: Enchytraeidae; Genus/Species: Not Determined; **Habitus: Phreatobite**.

D – Class: Annelida; Order: Clitellata; Family: Capilloventridae; Genus/Species: Capilloventer sp.; **Habitus: Stygobite.**

E – Class: Annelida; Order: Tubificida; Family: Naididae; Genus/Species: Nais sp.; **Habitus: Phreatobite**.

F – Class: Crustacea; Order: Syncarida; Family: Parabathynellidae; Genus/Species: c.f. Notobathynella sp.; **Habitus: Phreatobite**.

5.4 BASELINE GROUNDWATER LEVEL DATASETS

5.4.1 Spatial Groundwater Levels

As demonstrated by the datasets available in **Section 5.1**, the extensive groundwater monitoring network has a reasonable spatial distribution in the vicinity of the CQC Project, and are made more robust through the installation of the eastern/north-east drill hole(s) targeting the Styx Coal Measures basement (i.e. Permian Measures) to specifically address the DEE Submission Comments (**Table A1-3**). The new drill hole and installed VWP would allow future monitoring of the propagation of drawdown (if any in the basement aquifers) and validate the groundwater model predictions.

Inferred Depth to Groundwater Table / Unsaturated Profile

Section 10.5.6.2 and Figures 10-20 and 10-21 in CDM Smith (2018f) presents inferred water table elevation (and depth to groundwater) as well as general groundwater flow directions during wet seasons 2017/2018.

AMEC (2019) reports that the groundwater table occurs at a depth of 10 to 30 m below the surface.

Based on a review of the groundwater monitoring datasets (**Section 5.1**), with the exception of WMP23B, inferred to be within the Back Creek Group below the Styx Coal Measures (screened at 187-193 mbgl), recorded groundwater levels within the immediate CQC Project area generally shows minimal head separation between the upper stratigraphic sequences of the Early Cretaceous (Styx Coal Measures) and Cenozoic sediments. However, when the piezometric head surfaces of the lower stratigraphic sequences of the Early Cretaceous (Styx Coal Measures) are overlaid (i.e. WMP06 - Underburden), it appears that there is the potential for localised upward pressures from the underlying units, however based on the stable isotope analysis, such heads could potentially be influenced by surface water recharge of the groundwater system near the Tooloombah Creek pinch point (**Section 5.5.8**).

An inferred SWL elevation (based on available datasets compiled in the Cenozoic sediments and regolith is presented in **Figure 5-3**.

Corresponding depth to groundwater table surfaces have been generated based on the differences between the inferred SWL elevations and topographic datasets and presented in **Figure 5-4**.

5.4.2 Temporal Groundwater Levels and Historical Trends

Temporal groundwater levels and historical trends are evident in the hydrographs presented in **Attachment 8**.

The cumulative rainfall departure is presented on each hydrograph which shows in many groundwater monitoring bores the effects of the extended below average rainfall conditions experienced in the region since 2017, following Cyclone Debbie (**Graph 3-2**). It is however noted that groundwater datasets are also available in late 2010 (*n=1*), 2011 (*n=22*), 2012 (*n=18*) and 2014 (*n=5*) which coincided with average annual rainfall years (**Graphs 3-1 and 3-2**).

Historic groundwater levels were also noted on the Government database searches (**Attachment 4; Table A4-2**) at several landholder bore locations in the past few decades, however most were either one, or two historic records at most. The likely historical trends in groundwater pressures in the Styx Coal Measures as a result of historic coal mining in the Styx Coalfield from 1918 to 1964, and subsequent recovery is discussed separately in **Sections 3.4.5 and 6.3**.

Seasonal Fluctuations

The first recorded rainfall event since the installation of dataloggers in WMP04, WMP05 and WMP29A and the gauging stations on Deep Creek and Tooloombah Creek in September/October 2019 occurred in January 2020. A response (albeit <0.5 m) in the groundwater levels post the rainfall event at the furthest downstream groundwater monitoring bore WMP29A was evident (**Graph 3-5**).

The recorded alluvial groundwater datasets and relative change (magnitude) in stream levels in Tooloombah Creek and Deep Creek are shown in **Graphs 5-1 and 5-2**. As presented on all hydrographs in **Attachment 8** for relative comparison, each graph also shows the groundwater bore construction date, approximate drilled depth (brown), screen interval (grey) and stick-up (green). The key metrics are also listed on each graph.

A subtle response (albeit <0.5 m) in groundwater levels is evident at WMP05 consistent with the conceptualisation and TEM survey results (i.e. located within the mapped Qa unit [nearer to the watercourse] as opposed to the mapped Qpa unit). The WMP04 datalogger had not recorded a response to stream levels in Tooloombah Creek post the rainfall event.

Periodic Fluctuations

Periodic reductions in groundwater levels and subsequent recovery in some groundwater monitoring appear to coincide with bailing of bores for groundwater sampling and/or aquifer testing. Where relevant, notes have been included on the hydrographs in **Attachment 8**.

Tidal Fluctuations

As shown in **Graph 3-5**, twice daily perturbations consistent with high and low tides are evident with an amplitude of generally less than 5 cm to 10 cm at the downstream groundwater monitoring bore WMP29A, north of Ogmore.

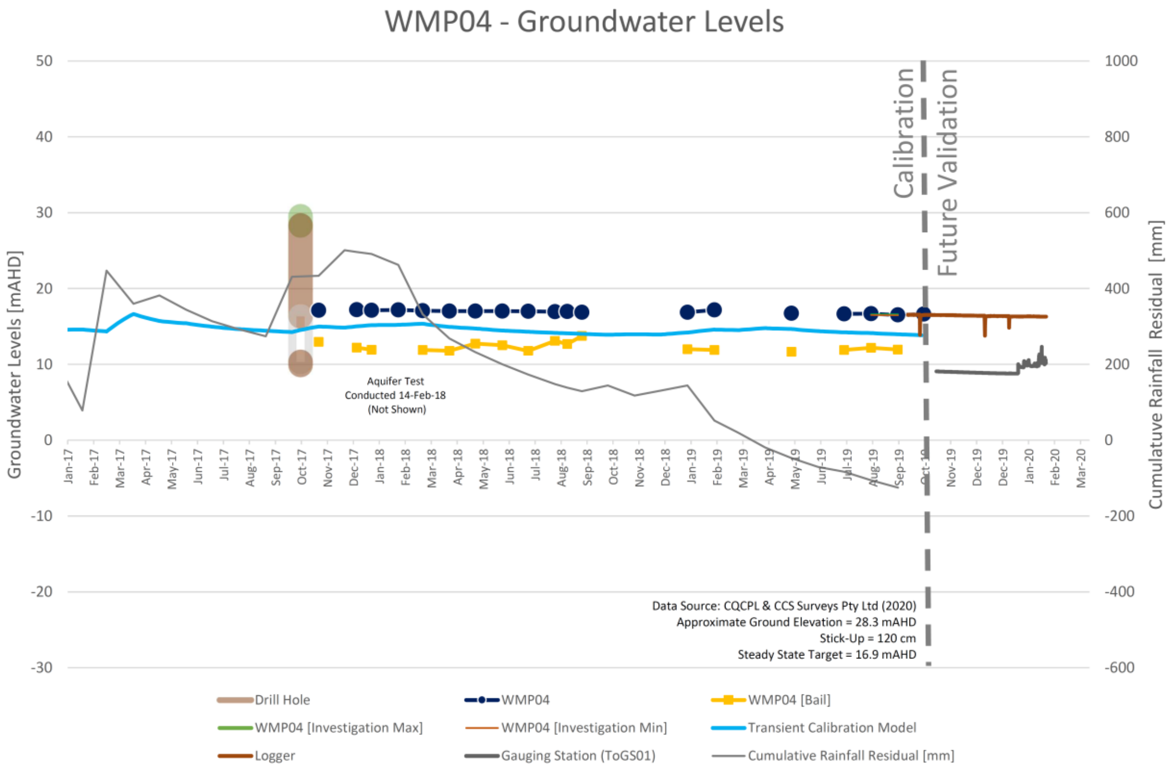
In contrast, the two groundwater monitoring bores at Tooloombah Creek and Deep Creek downstream of the CQC Project fitted with dataloggers (WMP04 and WMP05) show only a gradual reduction in line with the cumulative rainfall departure. As described above, WMP05 recorded a subtle response (albeit <0.5 m) in groundwater levels post the January-February 2020 rainfall events.

5.5 BASELINE GROUNDWATER QUALITY (AND OTHER SURFACE WATER QUALITY) DATASETS

Sections 10.5.4 and 10.5.6.5 of Chapter 10 of the SEIS prepared by CDM Smith provide detailed analysis of baseline groundwater quality (and comparisons with other surface water quality) datasets including:

- salinity (as EC) presented in Piper (trilinear) plots (SEIS Figure 10-8) and Stiff patterns (SEIS Figures 10-9 to 10-11) to compare cations and anions of surface waters, seawater and rainfall, as well as wet season and dry season analysis;
- pH and salinity (as EC and TDS), major ions and select dissolved metals of groundwaters in box and whisker (SEIS Figures 10-35 to 10-37), Piper (trilinear) plots (SEIS Figure 10-38), and Stiff patterns (SEIS Figure 10-39 to 10-46); and
- other dissolved metals, nutrients and hydrocarbons (SEIS Tables 10-46 to 10-67).

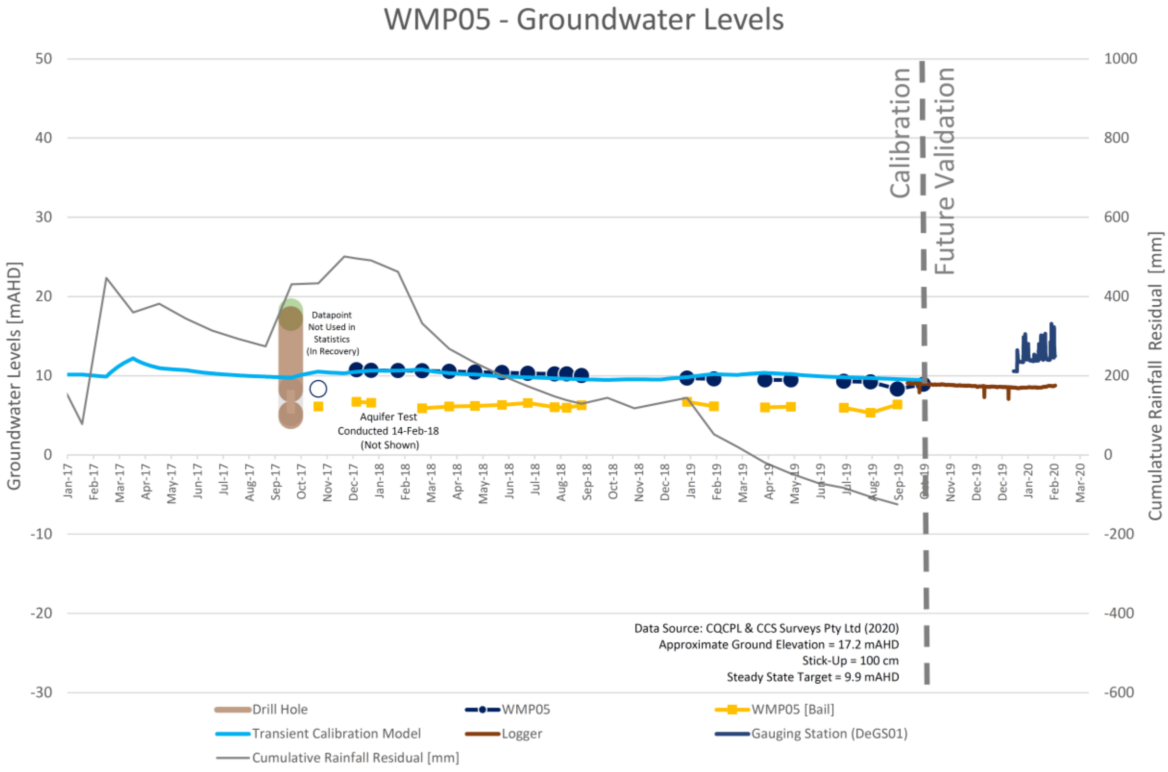
The groundwater quality analysis has not been repeated herein, however has been augmented with additional datasets collected during sampling by CQCPL in 2019 and relevantly presented in the following subsections.



Aquifer Test
Conducted 14-Feb-18
(Not Shown)

Data Source: CQCPL & CCS Surveys Pty Ltd (2020)
Approximate Ground Elevation = 28.3 mAHD
Stick-Up = 120 cm
Steady State Target = 16.9 mAHD

Graph 5-1
WMP04 Datalogger and Tooloombah Creek Gauging Station – Data Recorded Since Installation
[*Source: CQCPL, 2020*]



Datapoint
Not Used in
Statistics
(In Recovery)

Aquifer Test
Conducted 14-Feb-18
(Not Shown)

Data Source: CQCPL & CCS Surveys Pty Ltd (2020)
Approximate Ground Elevation = 17.2 mAHD
Stick-Up = 100 cm
Steady State Target = 9.9 mAHD

Graph 5-2
WMP05 Datalogger and Deep Creek Gauging Station – Data Recorded Since Installation
[*Source: CQCPL, 2020*]

For the purposes of comparison and discussion, and consistency with McNeil *et al*. (2018), the following groundwater quality salinity categories have been used:

- EC <200 µS/cm = very low
- EC <200–500 µS/cm = low
- EC >500–1,500 µS/cm = moderate
- EC >1,500–5,000 µS/cm = high [i.e. considered poor quality drinking water[xiv]]
- EC >5,000 µS/cm = very high [*or TDS 3,200 mg/L, based on 0.64 conversion factor*]

5.5.1 Quaternary Alluvium

For the purposes of the conceptual groundwater model, a summary of select physico-chemical parameters in Quaternary Alluvium are presented in **Table 5-10**. For the full suite of water quality analytes refer to the SEIS Version 3 (Appendix A5).

The groundwater quality results are generally consistent with the commentary made in the draft *Regional Groundwater Chemistry Zones: Fitzroy-Capricorn-Curtis Coast and Burdekin-Haughton-Don Regions Summary and Results* (McNeil *et al*., 2018) for the Aquifer Class / Chemistry Zone for Alluvium Zone 6 (Curtis Coast) (**Section 6.2**) which concludes:

> *'The water appears suitable for most purposes, although EC and TN may exceed QWQG aquatic ecosystem surface water quality guidelines, and pH (lower range values) may be below the guidelines in places.'*

5.5.2 Quaternary Pleistocene Alluvium / Regolith

For the purposes of the conceptual groundwater model, a summary of select physico-chemical parameters in Quaternary Pleistocene Alluvium are presented in **Table 5-11**. For the full suite of water quality analytes refer to the SEIS Version 3 (Appendix A5).

CDM Smith (2018e) relevantly noted that higher salinities were reported for alluvial groundwaters at WMP02, WMP04, WMP08, WMP09 and WMP26 compared to those closer to the Broad Sound (i.e. WMP29B).

These groundwater quality results for groundwaters inferred in Quaternary Pleistocene Alluvium/Regolith are generally consistent with the commentary made for the Aquifer Class / Chemistry Zone for Cainozoic Deposits including Deposits overlying GAB Zone 2 (Eastern Weathered Cainozoic Remnants) (McNeil *et al*., 2018) (**Section 6.2**) which concludes (emphasis in **bold**):

> *'… there are **occurrences of excessive salinity**. EC, pH (upper range values) and TN may exceed QWQG aquatic ecosystem surface water quality guidelines.'*

5.5.3 Tertiary Sediments

Historic groundwater quality datasets in the mapped Tertiary units (south-east of the CQC Project) are available at two groundwater bores listed on the Australian Groundwater Explorer / Qld Globe databases and summarised in **Table 5-12**.

Table 5-10

Groundwater Quality for Select Physico-chemical Parameters including Dissolved Metals and Nutrients – Quaternary Alluvium

Bore ID	Indicative Groundwater Quality [20th-80th %ile]		Salinity		Dissolved Metals [mg/L] [80th%ile]								TN [mg/L] [20th-80th %ile]
	pH	Alkalinity [mg/L]	EC [µS/cm]	TDS [mg/L]	Al	As	Fe	Mn	Mo	Se	V	Zn	
Quaternary Holocene Estuarine Alluvium													
WMP29A	7.4-7.7	441	3,060-**8,849**	**5,760**	-	0.006	-	-	-	-	-	0.024	-
BH05X	7.3-7.5	488	**9,393-12,362**	**8,920**	0.01	0.007	3.96	1.27	0.001	0.01	0.01	0.101	0.5
BH06X	7.3-8.0	483-719	1,572-2,269	832-922	0.01	0.004	0.452	0.133	0.001	0.01	0.01	0.021	33-62
BH25	7.2	486	**17,416-34,804**	**8,467**	-	-	0.1	-	-	-	-	-	-
Quaternary Alluvium													
WMP05	7.2-7.9	524-657	1,591-2,700	1,334-1,660	0.402	0.006	0.42	0.461	0.003	0.01	0.02	0.026	0.5-3.9
WMP21	Predominantly Dry [No Samples]												
BH01X	6.7-7.3	223-383	1,049-1,396	425-660	0.01	0.017	4.21	0.797	0.001	0.01	0.01	0.012	1.3-49
BH16	6.5-7.4	153-196	469-1,122	301-657	0.01	0.004	0.244	0.924	0.001	0.01	0.01	0.015	0.3-0.6
BH29	-	-	-	-	-	-	-	-	-	-	-	-	-

Source: After Orange Environmental Pty Ltd Database (7 January 2020).

Table 5-11

Groundwater Quality for Select Physico-chemical Parameters including Dissolved Metals and Nutrients – Quaternary Pleistocene Alluvium

Bore ID	Indicative Groundwater Quality [20th-80th %ile]		Salinity		Dissolved Metals [mg/L] [80th%ile]								TN [mg/L] [20th-80th %ile]
	pH	Alkalinity [mg/L]	EC [µS/cm]	TDS [mg/L]	Al	As	Fe	Mn	Mo	Se	V	Zn	
Quaternary Alluvium [Lower] (e.g. Qa, Qpa) / Regolith													
WMP02	6.6-7.2	406-446	**14,073-17,344**	**10,700-11,900**	0.016	0.002	0.056	0.392	0.002	0.01	0.01	0.005	3.8-4.8
WMP04	7.5-8.2	300-541	**11,361-19,660**	**8,136-15,080**	0.024	0.004	0.050	0.066	0.046	0.01	0.01	0.005	0.5-5.1
WMP08	6.7-7.3	637-721	**23,432-27,800**	**16,340-19,840**	0.010	0.003	0.068	1.314	0.003	0.01	0.01	0.025	0.5-1.8
WMP09	6.6-7.2	740-802	**20,095-22,200**	**13,972-15,200**	0.010	0.002	0.050	0.639	0.001	0.01	0.01	0.030	0.5-0.7
WMP12	7.0-8.6	310-528	3,034-**8,421**	2,920-**5,680**	0.120	0.005	0.090	0.167	0.008	0.01	0.01	0.010	10-32
WMP15	6.8-7.7	447-490	3,993-4,720	2,258-2,604	0.026	0.002	0.182	0.126	0.013	0.01	0.01	0.049	0.1-0.5
WMP17	7.2	-	**7,020**	-	-	-	-	-	-	-	-	-	-
WMP18	-	-	-	-	-	-	-	-	-	-	-	-	-
WMP25	5.9-6.6	45-47	799-1,001	588-616	-	0.002	-	-	-	-	-	0.314	-
WMP26*	6.7-7.0	892-908	**42,700-47,353**	**34,660-36,640**	-	0.005	-	-	-	-	-	0.139	-
WMP29B	6.7-7.6	417-421	**20,420-22,700**	**14,660-15,440**	-	0.025	-	-	-	-	-	0.070	-

Source: After Orange Environmental Pty Ltd Database (7 January 2020).

* WMP26 is screened above 7 mAHD, several metres above the long term mean sea level.

Table 5-12
Historic Groundwater Quality Test Results – Tertiary Sediments

Bore ID	Sample Date	pH	Alkalinity [mg/L]	EC [µS/cm]	Total Ions [mg/L]	Al [mg/L]	Fe [mg/L]	Mn [mg/L]	Zn [mg/L]
88889	Jul 1969	7.5	80	7,810	4,722	-	-	-	-
	Sep 1969	7.6	150	7,750	4,789	-	-	-	-
88891	Sep 1980	7.7	86	9,680	5,568	-	-	-	-
	Dec 1980	6.6	85	9,300	5,187	-	-	-	-

Source: Qld Government Groundwater Information Bore Reports (2019).

5.5.4 Styx Coal Measures

Groundwater quality testing was conducted at several exploration drill holes in 2014 as part of the aquifer testing at the Styx Trial Pit (AMEC, 2014). The results of the groundwater quality testing are presented in **Table 5-13** and indicated elevated (high) salinity levels in the Styx Coal Measures consistent with contemporary datasets.

Table 5-13
Groundwater Quality Test Results – November 2014

Drillhole	Easting	Northing	Hole Depth	pH [pH Units]	EC [µS/cm]	TDS [mg/L]
STX104	773234	7485348	81.5 mbgl	6.9	**22,300**	**14,495**
				7.6	**20,200**	**13,130**
				7.6	**24,500**	**15,925**
STX103	773375	7485206	82.0 mbgl	6.8	**19,700**	**12,805**
STX170	773169	7485265	66.0 mbgl	7.1	01800*	1,170*
STX204	773375	7485489	82.0 mbgl	6.8	**20,500**	**13,325**
STX205	773158	7485566	86.3 mbgl	7.5	**22,100**	**14,365**

Source: AMEC (2014; 2019).
* Reported values subject to confirmation.

For the purposes of the conceptual groundwater model, a summary of select physico-chemical parameters in the Styx Coal Measures are presented in **Table 5-14**. For the full suite of water quality analytes refer to the SEIS Version 3 (Appendix A5). Specific reference is made to recorded concentrations for analytes (Al, As, Fe, Mn, Mo, Se, V and Zn) which were identified during the prior geochemical assessments as part of the multi-element composition analysis on rock and solution extracts discussed in **Section 4.5**. CDM Smith (2018e) relevantly noted that the Styx Coal Measures is generally more saline than groundwater in all other units.

These groundwater quality results are generally consistent with the commentary made for the Aquifer Class / Chemistry Zone for Earlier Basins Partially Underlying GAB Zone 11 (Eastern Bowen Coal Measures) (McNeil, *et al*., 2018) (**Section 6.2**) which concludes (emphasis in **bold**):

> *'The water quality is poor for irrigation because sodium levels are excessive for sensitive crops (SAR >8), and EC may exceed irrigation guidelines in some bores. The water should be tested before giving to stock as there are* ***occurrences of excessive salinity****. Groundwater EC exceeds QWQG aquatic ecosystem surface water quality guidelines, and TN and pH (upper range values) may do also.'*

Table 5-14
Groundwater Quality for Select Physico-chemical Parameters including Dissolved Metals and Nutrients – Styx Coal Measures

Bore ID	Indicative Groundwater Quality [20th-80th %ile]				Dissolved Metals [mg/L] [80th%ile]								TN [mg/L] [20th-80th %ile]
	pH	Alkalinity [mg/L]	Salinity EC [µS/cm]	Salinity TDS [mg/L]	Al	As	Fe	Mn	Mo	Se	V	Zn	
Styx Coal Measures - Overburden (and Quaternary Alluvium [Lower]) / Weathered Regolith													
WMP04D	6.8-7.5	638-688	**23,161-26,100**	**15,800-17,200**	0.010	0.001	0.050	0.094	0.002	0.01	0.01	0.059	0.5-1.5
WMP10	6.9-7.5	1,160-1,290	**16,321-18,300**	**10,288-11,460**	0.014	0.002	0.050	0.566	0.030	0.01	0.01	0.013	1.1-2.4
WMP13*	6.2-7.0	504-524	**44,090-48,460**	**32,800-39,300**	0.050	0.005	0.920	1.912	0.005	0.05	0.05	0.043	0.5-0.9
WMP14	-	-	-	-	-	-	-	-	-	-	-	-	-
WMP21D	6.8-7.0	856-877	**37,740-40,797**	**27,760-30,040**	-	0.011	-	-	-	-	-	0.126	-
Styx Coal Measures - Overburden / Coal Seams and Interburden / Coal Seams													
WMP10D	-	-	-	-	-	-	-	-	-	-	-	-	-
WMP11	6.5-7.2	473-506	**29,611-32,328**	**20,172-23,340**	0.050	0.005	3.084	1.914	0.005	0.05	0.05	0.079	1.3-1.8
WMP11D	6.5-7.2	514-540	**30,280-31,893**	**20,760-22,660**	0.038	0.012	3.066	0.399	0.006	0.03	0.03	0.092	2.3-2.7
WMP17D	6.8-7.4	522-523	**36,080-39,403**	**26,240-27,860**	-	0.005	-	-	-	-	-	0.025	-
WMP18D	6.8-7.6	883-897	**27,700-30,700**	**22,020-22,680**	-	0.005	-	-	-	-	-	0.041	-
WMP22A	6.8-7.2	900-923	**22,720-24,400**	**15,120-16,080**	-	0.004	-	-	-	-	-	0.005	-
WMP22B	7.3-7.8	775-815	**29,540-33,479**	**21.080-21,620**	-	0.005	-	-	-	-	-	0.025	-
WMP23A	12.2-12.6^	3,104-3,116	**20,620-24,180**	**9,768-10,542**	-	0.004	-	-	-	-	-	0.161	-
WMP24	7.2-7.6	972-1,015	**20,300-23,000**	**13,940-14,660**	-	0.001	-	-	-	-	-	0.006	-
WMP27	-	-	-	-	-	-	-	-	-	-	-	-	-
WMP28	6.9-7.7	552-559	**6,058-6,412**	**3,518-3,752**	-	0.004	-	-	-	-	-	0.027	-
WMP29C	11.4-12.0^	285-351	**14,814-20,560**	**11,680-11,920**	-	0.006	-	-	-	-	-	0.012	-
WMP29D	10.9-11.2^	110-127	**17,700-19,900**	**12,060-12,840**	-	0.002	-	-	-	-	-	0.226	-
WMP30A	7.1-7.8	982-996	**22,400-24,700**	**15,920-17,780**	-	0.005	-	-	-	-	-	0.237	-
WMP30B	7.6-8.2	541-593	**21,800-25,600**	**15,720-15,780**	-	0.002	-	-	-	-	-	0.005	-
Styx Coal Measures – Underburden (and Quaternary Alluvium [Lower]) / Weathered Regolith													
WMP06	6.5-7.2	583-821	3,460-**5,770**	2,084-**3,338**	0.016	0.018	4.890	3.106	0.006	0.01	0.01	0.010	1.2-4.8
WMP07	-	-	-	-	-	-	-	-	-	-	-	-	-
WMP08D	7.3-7.7	263-278	**13,829-14,800**	**8,406-8,969**	0.030	0.004	0.380	0.333	0.001	0.01	0.01	0.028	0.8-1.1

Source: After Orange Environmental Pty Ltd Database (7 January 2020).

*WMP13 is located near Ogmore several kilometres downstream of ML 80187.

^Alkaline pH considered to be due to deep borehole construction (i.e. residual unset cement).

5.5.5 Permian Measures (Back Creek Group including Boomer Formation)

For the purposes of the conceptual groundwater model, a summary of select physico-chemical parameters in the Permian Measures are presented in **Table 5-15**. For the full suite of water quality analytes refer to the SEIS Version 3 (Appendix A5).

Table 5-15

Groundwater Quality for Select Physico-chemical Parameters including Dissolved Metals and Nutrients – Permian Measures

Bore ID	Indicative Groundwater Quality [20th-80th %ile]				Dissolved Metals [mg/L] [80th%ile]								TN [mg/L] [20th-80th %ile]
	pH	Alkalinity [mg/L]	Salinity										
			EC [µS/cm]	TDS [mg/L]	Al	As	Fe	Mn	Mo	Se	V	Zn	
Permian Measures - Back Creek Group (and Styx Coal Measures - Underburden)													
WMP29E	12.1-12.7^	3,028-3,142	**16,300-19,370**	**5,556-5,994**	-	0.002	-	-	-	-	-	0.042	-
WMP22C	9.8-10.3	271-273	**4,764-5,434**	**2,712-2,958**	-	0.002	-	-	-	-	-	0.011	-
WMP30C	7.8-8.0	574-591	**23,280-24,420**	**15,640-16,360**	-	0.016	-	-	-	-	-	0.005	-
WMP16	6.7-7.2	609-619	**9,460-10,500**	**5,864-5,876**	-	0.001	-	-	-	-	-	0.152	-
WMP16D	7.5-7.8	431-433	**8,399-9,338**	**4,760-4,970**	-	0.001	-	-	-	-	-	0.080	-
WMP19	6.7-7.3	529-539	1,908-2,182	1,144-1,156	-	0.004	-	-	-	-	-	0.100	-
WMP19D	6.4-7.2	526-535	1,922-2,262	1,098-1,212	-	0.006	-	-	-	-	-	0.053	-
WMP20	6.9	-	1,806	-	-	-	-	-	-	-	-	-	-
WMP20D	7.0-7.6	765-776	2,026-2,410	1,134-1,266	-	0.006	-	-	-	-	-	0.120	-
Permian Measures – Carmila Beds (and/or Back Creek Group)													
WMP23B	12.2-12.5^	2,508-3,102	**16,980-19,030**	**6,802-6,838**	-	0.002	-	-	-	-	-	0.022	-

Source: After Orange Environmental Pty Ltd Database (7 January 2020).

^Alkaline pH considered to be due to deep borehole construction (i.e. residual unset cement).

These results for groundwaters in the Permian Measures are generally consistent with the commentary made for the Aquifer Class / Chemistry Zone for Fractured Rock Zone 10 (Eastern Fitzroy Trap Rocks) (McNeil, *et al*., 2018) (**Section 6.2**) which concludes (emphasis in **bold**):

> *'**Groundwater EC exceeds QWQG aquatic ecosystem surface water quality guidelines**, as TN frequently does, and pH (upper range values) may also.'*

It is noted that several groundwater monitoring network bores have recorded pH levels in excess of 10 pH units. Following review and comparison of the available datasets, and previous experience, it is considered that the high pH levels are likely to be as a result of bore construction (e.g. residual unset cement) in the sampling column. Similarly, hydrocarbons have been observed at WMP30C and have been the subject of separate investigation by CQCPL and Orange Environmental Pty Ltd.

5.5.6 Lizzie Creek Volcanic Group (including Permian / Carmila Beds)

Historic groundwater quality datasets are available at several groundwater bores listed on the Australian Groundwater Explorer / Qld Globe databases and summarised in **Table 5-16**. Additional groundwater quality datasets available are also listed in **Table 5-7**.

5.5.7 Other Surface Water

The surface water quality datasets are discussed in **Section 3.2.7**. The following sub-sections provide a specific analysis of potential for groundwater and surface water connectivity.

Table 5-16
Historic Groundwater Quality Test Results – Lizzie Creek Volcanic Group (including Permian / Carmila Beds)

Bore ID	Sample Date (Year)	pH	Alkalinity [mg/L]	EC [µS/cm]	Total Ions [mg/L]	Al [mg/L]	Fe [mg/L]	Mn [mg/L]	Zn [mg/L]
91457	1965	8.0	373	1,340	1,008.5	-	-	-	-
88145	1965	6.8	459	2,850	1,905.5	-	-	-	-
111311	2000	7.8	500	13,400	8,752	0.00	0.00	0.05	0.18
111312	2000	8.2	395	4,700	3,031	0.00	0.00	0.28	0.22

Source: After Qld Government Groundwater Information Bore Reports (2019).

Styx River

As presented in **Table 3-4**, the salinity (EC) ranges are large at surface water sampling point St2 (4,884-37,800 µS/cm; 20th-80th%iles) reflecting the effects of tides and discharge of freshwater to sea following rainfall events. By comparison the salinity (EC) ranges are less pronounced at WMP29A (3,060-8,849 µS/cm; 20th-80th%iles), which when comparing the responses in groundwater levels recorded at WMP29A (albeit <0.5 m) post the recent January-February 2020 rainfall events appears to be consistent with the conceptualisation and application of fixed head conditions discussed in **Section 7.5.1**.

Tooloombah Creek

Since the installation of the Tooloombah Creek Gauging Station (ToGS01) in September/October 2019 and during the prevailing dry conditions in the second half of 2019, recorded salinity (EC) levels (**Graph 3-6**) in the pool upstream of ToGS01 was shown to be gradually increasing and over a three month period had more than doubled from 4,000 µS/cm to approximately 9,000 µS/cm. Separate pool water balance (i.e. evapo-concentration) analysis has been conducted by WRM Water & Environment (2020).

Post the January-February 2020 rainfall events, the recorded EC levels have reduced and since remained below approximately 500 µS/cm at ToGS01.

By comparison, the salinity (EC) levels recorded in groundwater monitoring bores WMP04 and WMP12 in the vicinity of ToGS01 ranged from (upgradient) 11,361-19,660 µS/cm (20th-80th%iles) to (downgradient) 3,034-8,421 µS/cm (20th-80th%iles). It is relevantly noted however that WMP12 is screened across two hydrogeological units and lowest screen point at approximately 9.4 mAHD. The lowest screen point in WMP04 is at approximately 10.3 mAHD. Further downgradient at WMP02 (with lowest screen point at approximately 7.0 mAHD) the salinity (EC) levels recorded at the groundwater monitoring bore ranged from 14,073-17,344 µS/cm (20th-80th%iles).

Notably, the furthest upstream groundwater monitoring location (WMP06) had also recorded gradually increasing salinity (EC) levels since mid-2018 from below 2,000 µS/cm to approximately 7,500 µS/cm in January 2020.

It has been recommended that salinity (EC) concentration levels be continued and recorded at WMP06 particularly in response to the rainfall events in the 1st quarter of 2020, to determine if the connectivity (i.e. recharge/leakage) from Tooloombah Creek toward the groundwater system was to result in similar EC reductions in line with the recorded low EC levels recorded at ToGS01 (**Graph 3-6**). Such data would validate and support the conceptualised flow direction from the watercourse to the aquifer and be consistent with the findings of the previous isotope analysis (**Section 5.5.8**).

Deep Creek

As discussed in **Section 3.2.7**, the surface water datasets recorded by AMEC in 2019 showed that the waterhole / pools monitored at Deep Creek 1 and Deep Creek 2 had been dry for the 2nd half of 2019. A subsequent inspection by CQCPL personnel in October 2019 confirmed the prevailing dry observations (**Plates 3-9 to 3-12**) and therefore no further water quality analysis was undertaken at the time beyond that previous reported by CDM Smith (2018e), including isotope sampling (**Section 5.5.8**).

However, CQCPL has since augmented the surface water quality datasets post the rainfall events in the 1st quarter of 2020 and are presented separately by Orange Environmental Pty Ltd (2020) and WRM Water & Environment (2020). As shown on **Graph 3-8**, pH and EC is recorded continuously with fluctuations generally reflecting the onset of rainfall runoff events and subsequent interflows in Deep Creek.

Corresponding subtle changes in groundwater levels at WMP05 are shown on **Graph 5-2** and discussed in **Section 5.4.2**.

5.5.8 Isotope Sampling

CDM Smith (2018e) conducted a preliminary study of stable isotopes of water (H-2 and O-18) in the Styx River catchment (including Deep Creek and Tooloombah Creek) as well as at targeted potential GDEs (Wetland 1, Wetland 2 and Alluvial Vine Thicket), and radioactive radon isotopes (Rn-222), and is presented in Section 6 of the Groundwater Technical Report (Appendix A6 of the SEIS).

Stable Isotope Study

Stable isotope analysis was conducted at the following groundwater monitoring bores and compared to the global meteoric water line (GMWL) and local meteoric water line (LMWL) developed from data collected by CSIRO (Crosbie *et al.* 2012):

- WMP02;
- WMP04;
- WMP04D;
- WMP05;
- WMP06; and
- WMP10.

As shown by Figure 6-1 in CDM Smith (2018f) (**Figure 5-5**), with the exception of WMP06, the groundwater sampling results plot on or at the GMWL and LMWL indicating that the groundwater sampled is derived mainly from rainfall recharge and has undergone little to no evaporation.

As discussed separately in **Section 5.1.2**, unlike the other groundwater monitoring bores sampled, WMP06 is located furthest west (and therefore in the stratigraphically lower sub-cropping units of the Styx Coal Measures) nearer to the confluence of Mamelon Creek and Tooloombah Creek (between Mt Brunswick and Mt Mamelon) in the regolith where a small unnamed tributary of Tooloombah Creek also drains the lower slopes of Mt Mamelon (i.e. Colluvium / Alluvial Fan Deposits [Qr, Qf > Kx]) (**Figures 4-2[a] and 4.3[a]**).

Tooloombah Creek and Deep Creek

Water samples were analysed (by Environmental Isotopes, via ALS) from in-stream pools on Tooloombah Creek and Deep Creek in July 2018 at each of the following surface water monitoring locations:

- To1 (To1.1 & To1.2), To2 (To2.1 & To2.2), and To3 (To3.1 & To3.2); and
- De2, De3 and De5.

As shown on **Figure 5-5**, the isotopic analysis of the surface water samples indicates that, consistent with the findings of Gonfiantini (1986), the ratio of residual isotopes O-18 to H-2 increases (relative to the groundwaters sampled) and is well below the GMWL and LMWL where water undergoes evaporation (i.e. progressively enriched with heavier isotopes).

The above findings are also generally consistent with the differences recorded in EC between the surface water pool levels and surface water quality and the groundwater level and groundwater quality measurements described in **Sections 5.1 and 5.4** and **Section 5.5**, respectively.

Potential GDEs

The theoretical approach adopted by CDM Smith (2018f) was based on similar tests used to evaluate the potential dependence of vegetation on groundwater (Eamus, 2009) with a specific focus on potential GDEs in the vicinity of the CQC Project, including:

- Wetland 1;
- Wetland 2; and
- the alluvial vine thicket assessment area (adjacent to Tooloombah Creek).

The stable isotope sampling was supplemented with shallow bore holes (BH1 to BH6)[23], vegetation sampling for leaf water potential (LWP) measurements and groundwater level monitoring (e.g. WMP25 and WMP27).

A summary of the relevant findings of CDM Smith (2018f) is presented below.

- **Wetland 1:** Groundwater level monitoring demonstrated that the standing water level of groundwater was greater than 10 mbgl and therefore no isotopic characterisation was performed below the vadose zone. Nevertheless, the available isotope data near the surface in the soil moisture profile indicated that vegetation at Wetland 1 was sourcing most water from the near surface.
- **Wetland 2:** Groundwater level monitoring demonstrated that the standing water level of groundwater was again greater than 10 mbgl and therefore no isotopic characterisation was performed below the vadose zone.
- **Alluvial Vine Thicket Assessment Area:** CDM Smith (2018f) indicated that the groundwater table was not encountered during drilling, thus the standing water groundwater level is at least 10 mbgl. The isotopic enrichment in the soil profile was mostly confined to the near surface (i.e. xylem water indicative of being sourced primarily from the top 0.5 m of the soil profile) and was concluded that there was no indication of groundwater use by the alluvial vine thicket vegetation.

At all three locations, CDM Smith (2018f) relevantly observed that much of the soil profile is very dry and well below the agronomic wilting point (i.e. -1.5 Mpa) for LWP, noting that native tree species can often tolerate soil moisture potentials well below this level.

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[23] With the exception of BH3 at 13.5 mbgl, all other shallow bore holes (BH1, BH2, BH4, BH5 and BH6) were dry.

The findings above are also generally consistent with the consideration of evapotranspiration and extinction depths (i.e. up to 8 mbgl) considered for maximum rooting depths of vegetation types (Canadell *et al.*, 1996 and Shah *et al*., 2007) for the purposes of this groundwater assessment, and is discussed separately in **Section 7.5.5**.

Similarly, it is noted in Jones *et al*. (2019) that the key finding of a separate study undertaken in southern Qld was despite maximum anticipated depth ranges of 12-23 mbgl based on literature studies (Kath *et al*., 2014) for maximum tree root depths, consistent maximum observed tree root depths of only 6-8 mbgl or shallower were recorded. These depths overlapped with zones of predicted moisture uptake from soil moisture and leaf water potential readings. With the regional groundwater table at depth, Jones *et al*. (2019) provided direct evidence of the ability of tree species that typically form GDEs (in the Great Artesian Basin) to source water from the most accessible source of available soil moisture which is not always the regional water table aquifer.

Radioactive Isotope Study

Six water samples were collected on Tooloombah Creek and Deep Creek (To1, To2, To3, De2, De3 and De5) in July 2018 and the methods and results presented in CDM Smith (2018f). Radioactive isotope analysis was undertaken at the Australian Nuclear Science and Technology Organisation (ANSTO) laboratory.

Based on the radioactive isotope results and relative comparison to chloride and bicarbonate/chloride concentrations[24], CDM Smith (2018f) relevantly concludes that there is a greater potential for groundwater contributions to Tooloombah Creek than Deep Creek, albeit not in any significant quantities.

This finding appears to align with the stable isotope result at WMP06 (upstream and furthest west of the CQC Project) and therefore in the stratigraphically lower sub-cropping units of the Styx Coal Measures. This also appears to be generally consistent with the inferred depths to groundwater between Mt Brunswick and Mt Mamelon as discussed in **Section 5.4.1** and shown on **Figure 5-4**.

5.5.9 Regional Groundwater Chemistry Zones (Draft) [McNeil *et al*, 2018]

Regional groundwater chemistry zones (draft) have been proposed for the Styx Basin by the DES and are outlined in McNeil *et al*. (2018) for the following Aquifer Class / Chemistry Zones applicable to the CQC Project area and surrounds:

- Alluvium Zone 6 (Curtis Coast);
- Cainozoic Deposits including Deposits overlying GAB Zone 2 (Eastern Weathered Cainozoic Remnants);
- Earlier Basins Partially Underlying GAB Zone 11 (Eastern Bowen Coal Measures); and
- Fractured Rock Zone 10 (Eastern Fitzroy Trap Rocks).

Water quality indicators in each of the above zones are presented for salinity (e.g. EC, cations and anions), acidity (e.g. pH, alkalinity), select metal concentrations (e.g. Fe, Mn, Zn) and nutrients (e.g. Total Phosphorus [TP], Total Nitrogen [TN]) in McNeil *et al*. (2018).

Subsequent consultation with DES in November 2019 confirmed that technical updates are being made since the 2018 consultation material was published for public comment but there was no timeframe for when the work will be completed and available. Nevertheless, the four (4) regional groundwater chemistry zones (draft) have been considered and are relevantly discussed in **Section 6.2**.

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[24] Assuming radon, bicarbonate and chloride are higher in groundwater than surface water, consistent with the findings of O'Grady *et al.* (2007).

5.6 HYDRAULIC PROPERTIES (AQUIFER TESTING, LITERATURE REVIEW AND PRIOR MODELLING)

Aquifer Testing (CDM Smith, 2018g)

A comprehensive program of aquifer testing was completed by CDM Smith (2018g) including a combination of testing methods and analysis solutions including:

- falling head slug testing (using Hvorslev [1951] solution);
- falling head slug testing (using Bouwer-Rice [1976] solution);
- rising head slug testing (using Bouwer-Rice [1976] solution);
- rising head constant rate recovery testing (using Theis [1935] solution); and
- rising head airlift recovery testing (using Cooper-Jacob [1946] solution).

In total, 73 separate hydraulic conductivity test estimations across 31 groundwater monitoring locations at the CQC Project were completed. An overview of the previous aquifer testing results, and additional aquifer testing completed in 2019 is provided in the following subsections. It is noted that several (WMP04D, WMP06, WMP12, WMP13, WMP20, WMP21D, WMP27) of the 31 groundwater monitoring locations are screened across the two hydrogeological units (e.g. alluvium, regolith and/or coal measures) which does not allow separate responses to be investigated, nevertheless have been considered.

Literature Review and Prior Numerical Groundwater Model Parameterisation

Many literature review compilations, based on testwork programs and prior modelling assessments, have been undertaken in Eastern Australia to derive representative hydraulic properties of the different stratigraphic units for the purposes of numerical groundwater modelling.

A review of hydraulic properties based on aquifer testing, published reports and prior modelling conducted by CDM Smith (2018g) has been considered in the development of the improved numerical groundwater model (**Table 5-17**). The previously modelled CDM Smith (2018g) hydraulic properties used are annotated in <**bold**> for comparison as well as the parameter ranges explored during the uncertainty analysis. Further details relating to the CDM Smith (2018g) review of hydraulic properties are available separately but is not duplicated in full herein.

Whilst the descriptions below in the following subsections are not necessarily exhaustive, and may not include all contemporary datasets in the broader region, this summary is provided to adhere to the Principle of Parsimony or ‘Occam’s Razor’.

As noted in CDM Smith (2018g):

> *‘Overly simplistic models fail to capture signal (i.e. they underfit the data and provide poor prediction).’*
> …
> *‘With an over-parameterized approach, a better calibration (at the cost of a more computational effort) can be achieved as locally defined parameters can adjust to local observation. …*

Relevantly, the Peer Review of the prior numerical groundwater model approach adopted by CDM Smith (2018a) by HydroAlgorithmics (2019) relevantly concluded:

> *Vertical hydraulic conductivity in the coal measures should be much lower than horizontal hydraulic conductivity; at present they are assumed equal.*

Thus, the relative consideration of anisotropy was a focus to support the improved model parameterisation.

Table 5-17
Hydraulic Properties Review of Indicative Datasets (Source: After CDM Smith, 2018g)

Stratigraphic Unit	Hydraulic Conductivity		Specific Yield	Specific Storativity
	$K_{\text{Horizontal}}$ [m/day]	K_{Vertical} [m/day]	S_y [-]	S_s [1/m]
Alluvium [*Quaternary*]	0.0001 – 10	0.025	0.05	0.0001
	<**4.1**> ***150***	<**0.41**> ***150***	<**0.01**>	<**0.000005**>
Fractured and Weathered Basement / [*Regolith*]	0.001 – 33	0.025	0.05	0.0001
	<**1.0**>	<**0.1**>	<**0.005**>	<**0.000005**>
Styx Coal Measures (Overburden) *[Early Cretaceous]*	0.0075	0.00075	0.01	0.00001
	0.0017 <**0.02**> ***0.17***	***0.0017*** <**0.02**> ***0.17***	<**0.005**>	<**0.000005**>
Styx Coal Measures (Coal [& Interburden]*) [*Early Cretaceous*]	0.0001 – 0.22	0.00001 – 0.022	0.01	0.00001
	0.001 **<0.003>** ***2.5***	***0.001*** **<0.003>** ***2.5***	**<0.005>**	<**0.000005**>
Styx Coal Measures (Underburden) [*Early Cretaceous*]	0.005	0.0005	0.01	0.00001
	0.001 **<0.004>** ***0.1***	***0.001*** **<0.004>** ***0.1***	**<0.005>**	<**0.000005**>
Styx Coal Measures (Bulk) [*Early Cretaceous*]	0.00005 – 46	-	-	-
Unweathered Basement [Back Creek Group / Boomer Formation] [*Permian*]	0.00001 – 0.1	**-**	**-**	-
	0.0004 – 0.1	0.00001 – 0.003	0.0005 – 0.02	0.000006 – 0.0005
	<0.0004> ***0.044***	**<0.0004>** ***0.044***	**<0.005>**	<**0.000005**>
Unweathered Basement [Carmila Beds] [*Permian*]	0.00001 – 0.1	-	-	-
	<0.0004> ***0.044***	**<0.0004>** ***0.044***	**<0.005>**	<**0.000005**>
Lizzie Creek Volcanic Group	0.0000001	0.000001	0.0001	0.000001
Connors Volcanic Group	0.00001	-	-	-

Source: After Table 10-12 in CDM Smith (2018g).
* Coal and interburden was modelled in the one layer in the CDM Smith (2018g) model.

The updated conceptual groundwater modelling approach, considering the above, is therefore discussed in **Section 6.3**. A collective graphical summary of aquifer testing datasets described in the proceeding subsections is also presented for ease of relative comparison (including tested interval depths at an equivalent scale) on **Graphs 5-3 to 5-8**. For ease of reference, the colours shown on the graphs (and later tables in **this Report**) have been applied to be generally consistent with and correlate with the mapped geological units *viz*.:

Turquoise = Quaternary Holocene Estuarine Alluvium

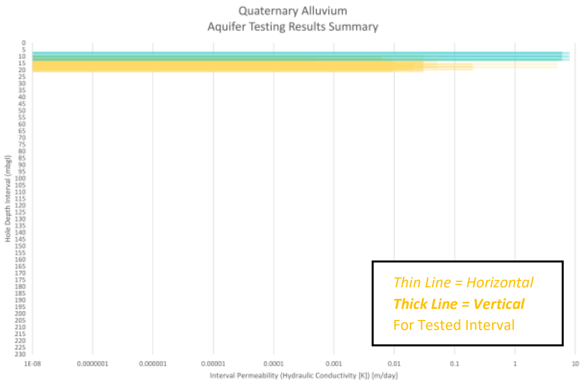
Light Yellow = Quaternary Alluvium (Holocene)

Orange = Quaternary Pleistocene Alluvium

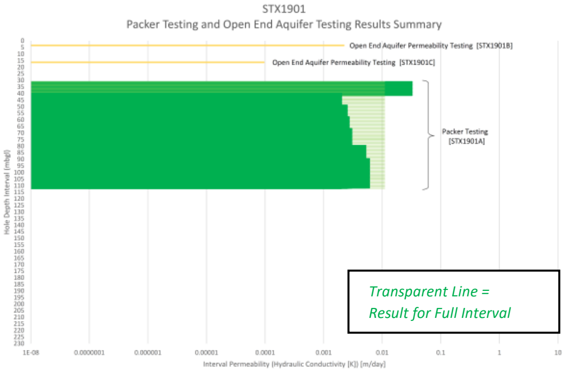
Brown = Tertiary Sediments

Green = Styx Coal Measures

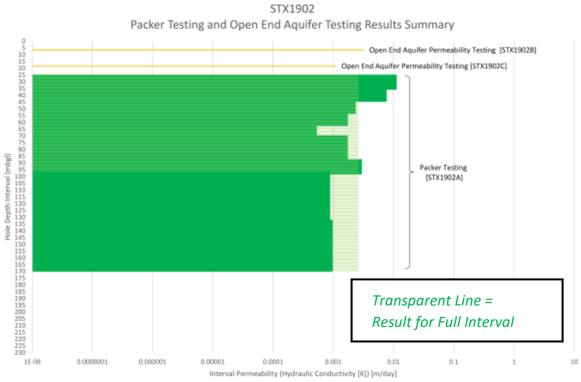
Blue = Permian Back Creek Group



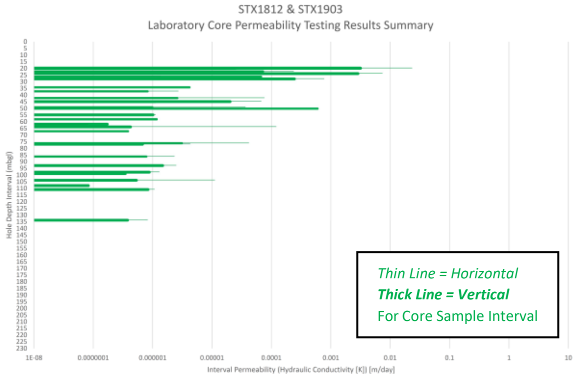
Graph 5-3
Previous Aquifer Test Results – [Qa / Qpa / Qhe]
[Source: After CDM Smith, 2018g]



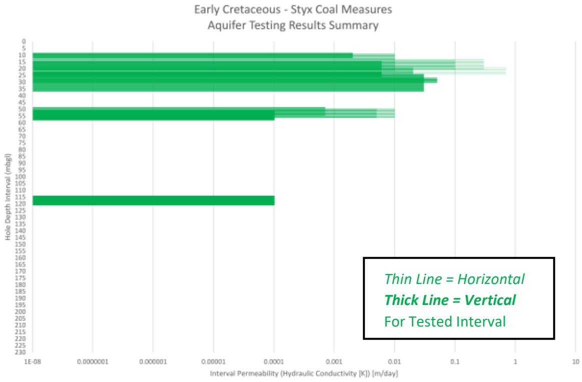
Graph 5-4
Packer (STX1901) & Open Aquifer Test Results [Qpa / Kx]
[Source: After AMEC, 2019]



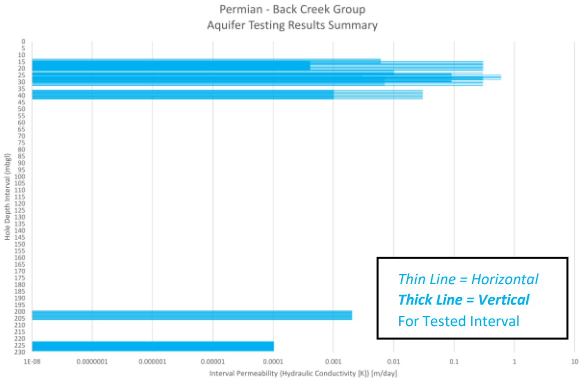
Graph 5-5
Packer (STX1902) & Open Aquifer Test Results [Qpa / Kx]
[Source: After AMEC, 2019]



Graph 5-6
Laboratory Core Permeability Test Results [Kx]
[Source: After GES, 2019]



Graph 5-7
Previous Aquifer Test Results – [Kx]
[Source: After CDM Smith, 2018g]



Graph 5-8
Previous Aquifer Test Results – [Pb]
[Source: After CDM Smith, 2018g]

5.6.1 Quaternary Alluvium

The hydraulic properties of alluvium are typically variable due to the heterogenous distribution of sediments (i.e. fine clays to coarse gravels).

Based on a review of the nine (9) groundwater monitoring bores inferred to be in alluvium of Quaternary age (Qa, Qpa, Qhe) at the CQC Project by CDM Smith (2018g), five (5) aquifer test solutions were determined within the mapped extent of Qa (and Qhe) units:

- **WMP05 (Qa):**
  - Falling Head Slug Test (Bouwer-Rice Solution): 0.03 m/day.
  - Falling Head Slug Test (Hvorslev Solution): 0.07 m/day.
- **WMP29A (Qhe):**
  - Falling Head Slug Test (Bouwer-Rice Solution): 6 m/day (early).
  - Falling Head Slug Test (Bouwer-Rice Solution): 8 m/day (late).
  - Rising Head Slug Test (Bouwer-Rice Solution): 7 m/day (early).

The results of the aquifer testing of the remaining Quaternary age alluvium groundwater monitoring bores (Qpa) are presented in **Section 5.6.2**.

As observed elsewhere in the Bowen Basin, it is noted that alluvium of Quaternary age is generally made up of a series of sand/gravel lenses that are limited in both horizontal and vertical extent and separated from other lenses by significantly less permeable clays. CDM Smith (2013) presented a comprehensive summary of hydraulic properties used in previous studies in the Bowen Basin which was augmented by HydroSimulations (2014) with several other studies from the Bowen Basin and Galilee Basin and is reproduced in **Table 5-18**.

Table 5-18
Hydraulic Properties Review for Quaternary and Tertiary Age Units (HydroSimulations, 2014)

Stratigraphic Unit	Hydraulic Conductivity		Specific Yield	Specific Storativity	Original Source
	K $_{Horizontal}$ [m/day]	K $_{Vertical}$ [m/day]	S_y [-]	S_s [1/m]	
Alluvium [Quaternary / Tertiary]	1 – 40	-	0.05 – 0.18	0.0005	Ausenco-Norwest (2012)
	100	10	0.25	0.001	AGE Consultants (2006)
	0.7-1.5	-	-	-	JBT (2012)
	10	1	0.2	0.0001	Matrix Plus (2012)
	0.088-0.38	-	-	-	URS (2009)
	10	1	0.1	0.00001	CDM Smith (2013)
	<**4.1**> ***150***	<**0.41**> ***150***	<**0.01**>	<**0.000005**>	CDM Smith (2018g)

Source: After HydroSimulations (2014) [after CDM Smith (2013)].

Domenico & Schwartz (1990) report estimates of hydraulic conductivity for medium sand in the range of 0.1 m/day to 45 m/day (McNeil, *et al*., 2018). Furthermore, as a comparison, Arrow Energy (URS, 2012) assigned a hydraulic conductivity value of 2 m/day to the base case numerical groundwater flow model to represent floodplain alluvium within the Bowen Basin.

5.6.2 Quaternary Pleistocene Alluvium / Regolith

As noted in **Section 4.3.2** by CQCPL's geologists, clay was by far the most frequently encountered material within the Quaternary age sediment (Quaternary Pleistocene Alluvium [Qpa]) across the CQC Project area. Eight (8) groundwater monitoring bores inferred to be in alluvium of Quaternary age (including Qpa) at the CQC Project by CDM Smith (2018g) were tested for aquifer properties and twelve (12) aquifer test solutions were determined as follows:

- **WMP02:**
  - Rising Head Constant Rate Recovery Test (Theis Solution): 5 m/day.
- **WMP04:**
  - Falling Head Slug Test (Bouwer-Rice Solution): 0.01 m/day.
  - Falling Head Slug Test (Hvorslev Solution): 0.02 m/day.
- **WMP08:**
  - Falling Head Slug Test (Bouwer-Rice Solution): 0.0005 m/day.
- **WMP09:**
  - Falling Head Slug Test (Bouwer-Rice Solution): 0.1 m/day.
  - Falling Head Slug Test (Hvorslev Solution): 0.2 m/day.
- **WMP12:**
  - Rising Head Constant Rate Recovery Test (Theis Solution): 2 m/day.
- **WMP25:**
  - Falling Head Slug Test (Bouwer-Rice Solution): 0.006 m/day.
- **WMP26:**
  - Falling Head Slug Test (Bouwer-Rice Solution): 0.03 m/day (early).
  - Falling Head Slug Test (Bouwer-Rice Solution): 0.009 m/day (mid/late).
- **WMP29B:**
  - Falling Head Slug Test (Bouwer-Rice Solution): 0.2 m/day (early).
  - Falling Head Slug Test (Bouwer-Rice Solution): 0.02 m/day (mid).
  - Rising Head Slug Test (Bouwer-Rice Solution): 0.2 m/day (early).
  - Rising Head Slug Test (Bouwer-Rice Solution): 0.02 m/day (mid).
  - Rising Head Slug Test (Bouwer-Rice Solution): 0.1 m/day (late).

The aquifer test results are presented in Attachment B of Appendix 6 in CDM Smith (2018g).

2019 Aquifer Testing Program (AMEC, 2019)

A summary of the results of site-specific open end permeability test results conducted at the four shallow observation holes (i.e. STX1901B; STX1902B; STX1901C; STX1902C) that were used to support the packer testing holes (**Section 5.6.4**) between the proposed open cut and Tooloombah Creek and Deep Creek respectively is presented in **Table 5-19**.

Table 5-19
Open End Permeability Test Results (After AMEC, 2019)

Location	Observation Hole	Easting	Northing	Aquifer Test Interval	Interval Permeability [Hydraulic Conductivity (K)]	
					(m/sec)	(m/day)
Between Tooloombah Creek and Open Cut 2	STX1901B	772356	7489012	~3+ mbgl (28.8 mAHD) [*Qpa – Upper* {Unsaturated}]	2.5 x 10^{-8}	[2.2 x 10^{-3}]
	STX1901C	772380	7489009	~16+ mbgl (14.4 mAHD) [*Qpa – Lower / Regolith* {Unsaturated}]	1.0 x 10^{-9}	[9.5 x 10^{-5}]
Between Deep Creek and Open Cut 1 and 2	STX1902B	774639	7485932	~6+ mbgl (23.9 mAHD) [*Qpa – Upper* {Unsaturated}]	3.7 x 10^{-8}	[3.2 x 10^{-3}]
	STX1902C	774623	7485923	~18+ mbgl (11.8 mAHD) [*Qpa – Lower / Regolith* {Unsaturated}]	1.3 x 10^{-8}	[1.1 x 10^{-3}]

Source: After AMEC (2019) with unit conversion in parentheses [].

The open end aquifer permeability test results demonstrate that the Cenozoic Sediments at depth (i.e. Pleistocene Alluvium / Regolith) have a relatively lower interval permeability than the upper units at the respective test locations (i.e. 3 to 23 times less).

As observed elsewhere in the Bowen Basin (SKM, 2014) the concept is generally accepted that alluvium is made up of a series of sand/gravel layers or lenses that are limited in both horizontal and vertical extent and separated from other layers or lenses by significantly less permeable clays. These interval testwork results further support the groundwater conceptualisation described in **Section 6.1.1** to delineate the upper units in the numerical model for assessment purposes.

Quaternary Colluvium / Alluvial Fan Deposits

Colluvium typically accumulates at the foot of slopes (due to gravity) and as described in **Section 4.3.3** is locally mapped west and south-west of the CQC Project at the lower slopes of the elevated landforms associated with Mt Mamelon which topographically drains a small unnamed tributary northward toward Tooloombah Creek. The hydraulic properties of colluvium can typically be expected to be in the range of alluvium and regolith at the surface.

Unconsolidated Sediments Specific Storage (S_s)

Rau *et al*. (2018) uses a method to demonstrate that, despite the potential derivation of higher values using hydraulic testing, a physical upper limit of 1.3 x 10^{-5} m^{-1} should be applied for unconsolidated material in numerical groundwater models. However, contemporary modelling examples suggest this 'limit' does not necessarily provide a better calibration result when history-matching. Therefore, for the purposes of the uncertainty analysis (**Attachment 11**), the ranges / distributions have not been constrained and is discussed in **Section 8.11**.

5.6.3 Tertiary Sediments

It is recognised that within and in the immediate surrounds of the CQC Project there are no mapped Tertiary units (Malone, 1964). The nearest mapped Tertiary units (Ta, Td, TQr) are located more than 10 km to the south-east of the mine tenements (**Section 4.3.5**). Nevertheless, literature estimates for Tertiary age units are also summarised in **Table 5-18**.

5.6.4 Styx Coal Measures (Overburden and Interburden)

Eleven (11) groundwater monitoring bores inferred to be in overburden of the Styx Coal Measures at the CQC Project were tested for aquifer properties and 17 aquifer test solutions were determined as follows:

- **WMP04D:**
    - Falling Head Slug Test (Bouwer-Rice Solution): 0.02 m/day.
    - Falling Head Slug Test (Hvorslev Solution): 0.03 m/day.
- **WMP10:**
    - Falling Head Slug Test (Bouwer-Rice Solution): 0.004 m/day.
- **WMP13:**
    - Falling Head Slug Test (Bouwer-Rice Solution): 0.3 m/day.
- **WMP17D:**
    - Falling Head Slug Test (Bouwer-Rice Solution): 0.08 m/day (mid).
    - Falling Head Slug Test (Bouwer-Rice Solution): 0.01 m/day (late).
    - Rising Head Slug Test (Bouwer-Rice Solution): 0.3 m/day (early).
    - Rising Head Slug Test (Bouwer-Rice Solution): 0.06 m/day (mid).
- **WMP18D:**
    - Falling Head Slug Test (Bouwer-Rice Solution): 0.7 m/day (early).
    - Falling Head Slug Test (Bouwer-Rice Solution): 0.02 m/day (mid/late).
- **WMP21D:**
    - Falling Head Slug Test (Bouwer-Rice Solution): 0.1 m/day.
- **WMP22A:**
    - Rising Head Slug Test (Bouwer-Rice Solution): 0.05 m/day.
- **WMP23A:**
    - Falling Head Slug Test (Bouwer-Rice Solution): 0.0007 m/day.
- **WMP24:**
    - Falling Head Slug Test (Bouwer-Rice Solution): 0.005 m/day.
    - Falling Head Slug Test (Hvorslev Solution): 0.006 m/day.
- **WMP27:**
    - Falling Head Slug Test (Bouwer-Rice Solution): 0.006 m/day.
- **WMP28:**
    - Falling Head Slug Test (Bouwer-Rice Solution): 0.002 m/day.

2019 Laboratory Core Permeability Testing Program (GES, 2019; 2020)

Groundwater Exploration Services Pty Ltd (GES) (2020) (**Attachment 9**) undertook representative drill core interval sampling in two exploration holes STX1812 [772085; 7488725] (from approximately 20 m to 100 m) and STX1903 [773391, 7486731] (from approximately 20 m to 135 m) at the CQC Project and coordinated laboratory permeability testing (vertical and horizontal) to determine hydraulic conductivity properties. The locations of STX1812 and STX1903 are shown on **Figure 5-1[c]**.

A summary of the laboratory core permeability results is presented in **Table 5-20** and the original laboratory data presented graphically on **Graph 5-9 (and Graph 5-6)**. It is noted that the term permeability of the strata is with respect to water and not *intrinsic* permeability. For the purposes of comparison for the conceptual groundwater model (**Section 6.0**), the arithmetic and harmonic means for the horizontal and vertical hydraulic conductivities respectively determined are presented. Further details are provided in **Attachment 9**.

Eight (8) tests for total porosity and effective porosity (or specific yield) was also undertaken on a representative sub-sample of the stratigraphic column (**Attachment 9**). The average total porosity was 9.7% and average effective porosity was 1.1% (*NB: this is comparable to the maximum Sy values used in the numerical groundwater model discussed in **Section 7.7.3***). GES specifically note that based on the sample set able to be successfully tested, the test data results are considered to be toward the higher values of permeability and porosity (**Attachment 9**).

2019 Aquifer Testing Program (AMEC, 2019)

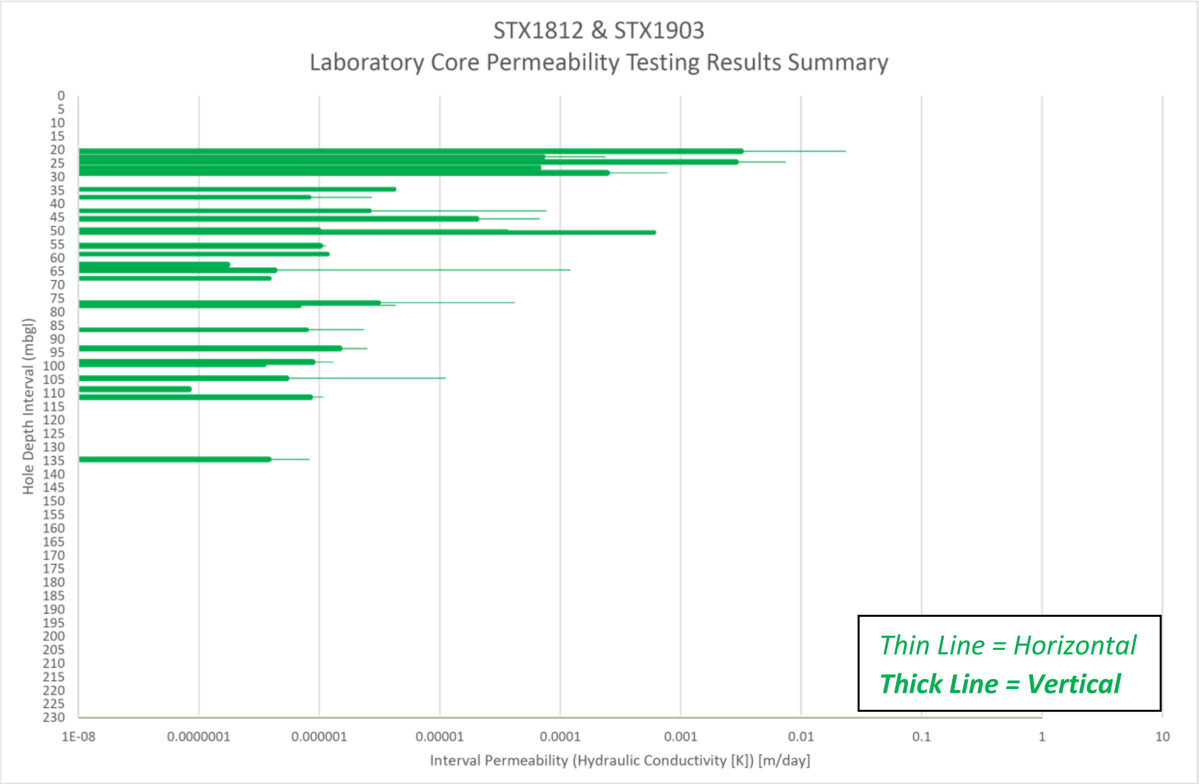
A summary of the results of packer testing conducted at two exploration holes (STX1901A and STX1902A) by AMEC (2019) is provided below.

Each of the packer test holes (STX1901A and STX1902A) were supported with two shallow observation holes at lateral distances of 10 m and 20 m respectively (i.e. STX1901B/STX1902B and STX1901C/ STX1902C) (**Figure 5-3**). A summary of the open end aquifer permeability test results at the observation holes are provided in **Section 5.6.2**. The packer testing at STX1901A and STX1902A targeted the Styx Coal Measures sequence from the surface to the approximate base of the proposed open cut (e.g. approximately 100 mbgl and 158 mbgl, respectively) and slightly beyond (approximately 10 to 15 m). The results of the packer testing are shown graphically (**Graphs 5-10 and 5-11**) and summarised separately in **Table 5-21**. Importantly, it is noted that the intervals to which the packer testing was applied varied and is presented accordingly to allow appropriate interpretation.

Table 5-20
Laboratory Core Permeability Testing Results at STX1812 and STX1903 (GES, 2020)

Formation	Averaging Interval	Total Sample Count^		Interval Permeability [Hydraulic Conductivity (K)] (m/day)		
				Minimum	Mean*	Maximum
Styx Coal Measures	Overburden & Interburden (Regolith to Red Lower)	13	[6] Horizontal	1.4 x 10^{-6}	**4.3 x 10^{-3}**	2.3 x 10^{-2}
			[7] Vertical	2.0 x 10^{-5}	**5.7 x 10^{-5}**	3.2 x 10^{-3}
	Interburden (Red Lower to Blue Lower)	32	[15] Horizontal	8.3 x 10^{-8}	**1.9 x 10^{-5}**	1.2 x 10^{-4}
			[17] Vertical	8.3 x 10^{-8}	**4.8 x 10^{-7}**	6.0 x 10^{-4}
	Interburden (Blue Lower to Violet Lower)	5	[2] Horizontal	2.3 x 10^{-6}	**2.2 x 10^{-5}**	4.2 x 10^{-5}
			[3] Vertical	6.7 x 10^{-7}	**5.2 x 10^{-7}**	1.5 x 10^{-6}

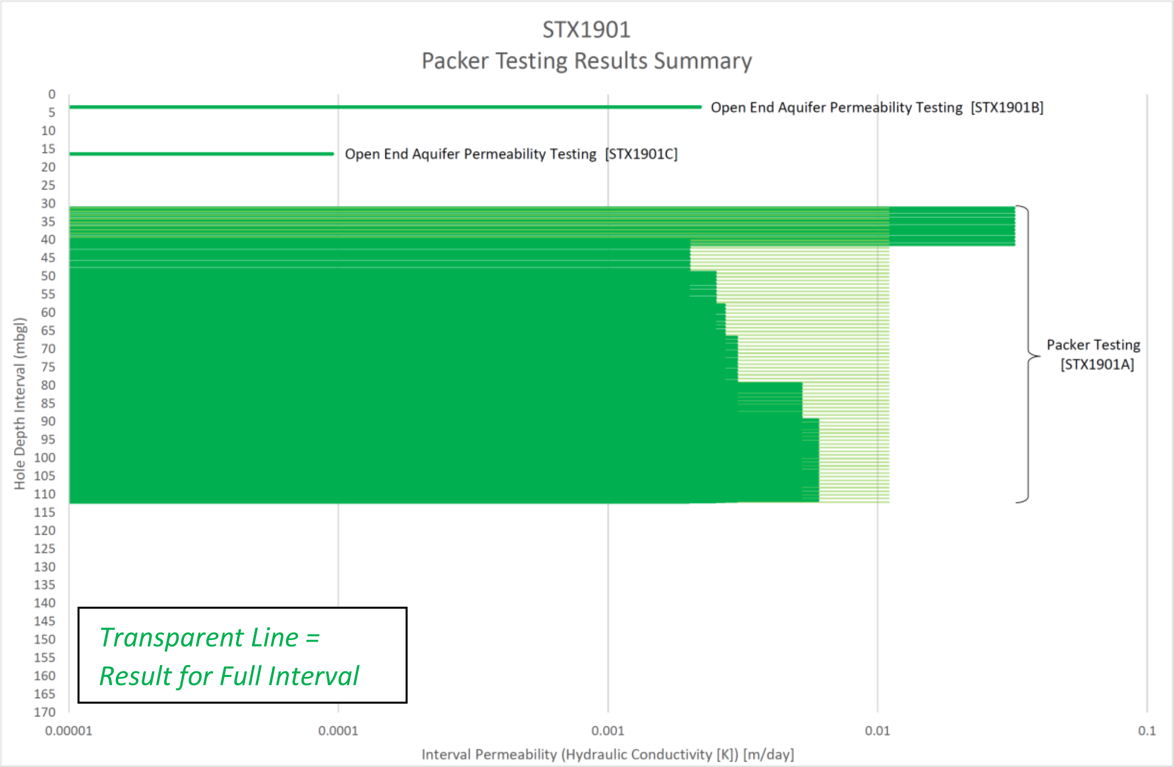
Source: After GES (2020).
^ Excludes all failed and/or fractured samples.
* *NB: Arithmetic Mean presented for Horizontal Permeability; Harmonic Mean presented for Vertical Permeability.*



Graph 5-9

STX1812 & STX1903 Laboratory Core Permeability Testing Results Summary

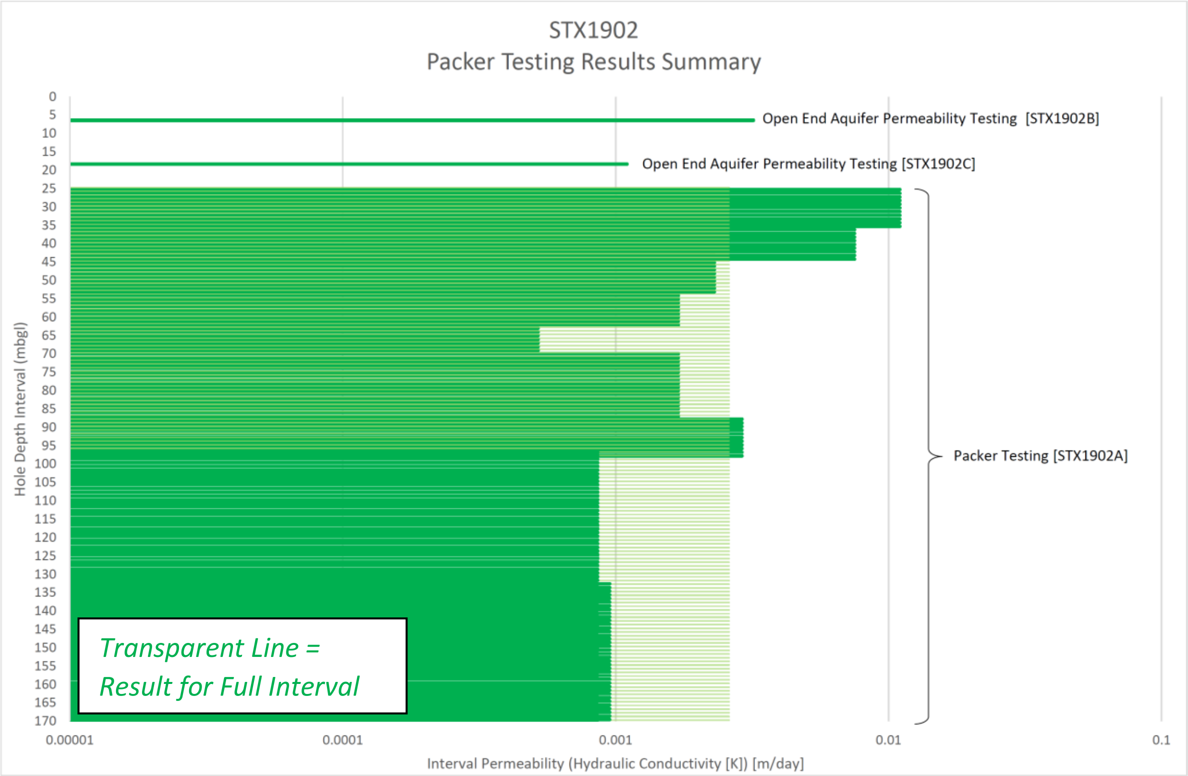
[Source: After GES, 2019*[xv]*]



Graph 5-10

STX1901 Packer Testing Results Summary

[Source: After AMEC, 2019]



Graph 5-11
STX1902 Packer Testing Results Summary
[*Source: After AMEC, 2019*]

Table 5-21
Packer Testing Results at STX1901 and STX1902 (After AMEC, 2019)

Location (Observation Hole)	Easting	Northing	Aquifer Test Interval	Interval Permeability [Hydraulic Conductivity (K)] (m/sec)	(m/day)
Between Tooloombah Creek and Open Cut 2 (STX1901A)	772362	7488999	31-41 mbgl (-5.4 to -14.4 mAHD) [*Kx [Coal Seams & Interburden]*]	3.7 x 10^{-7}	[3.2 x 10^{-2}]
			31-112 mbgl (from -5.4 mAHD) [*Kx [Coal Seams & Interburden]*]	1.3 x 10^{-7}	[1.1 x 10^{-2}]
			40-112 mbgl (from -14.4 mAHD) [*Kx [Interburden & Coal Seams]*]	2.3 x 10^{-8}	[2.0 x 10^{-3}]
			49-112 mbgl (from -23.4 mAHD) [*Kx [Interburden & Coal Seams]*]	2.9 x 10^{-8}	[2.5 x 10^{-3}]
			58-112 mbgl (from -32.4 mAHD) [*Kx [Interburden & Coal Seams]*]	3.1 x 10^{-8}	[2.7 x 10^{-3}]
			67-112 mbgl (from -41.4 mAHD) [*Kx [Coal Seams & Interburden]*]	3.5 x 10^{-8}	[3.0 x 10^{-3}]
			76-112 mbgl (from -50.4 mAHD) [*Kx [Interburden & Coal Seams]*]	3.0 x 10^{-8}	[2.6 x 10^{-3}]
			80-112 mbgl (from -54.4 mAHD) [*Kx [Coal Seams & Interburden]*]	6.0 x 10^{-8}	[5.2 x 10^{-3}]
			90-112 mbgl (from -64.4 mAHD) [*Kx [Coal Seams & Interburden]*]	6.9 x 10^{-8}	[6.0 x 10^{-3}]

Table 5-21 (Continued)
Packer Testing Results at STX1901 and STX1902 (After AMEC, 2019)

Location (Observation Hole)	Easting	Northing	Aquifer Test Interval	Interval Permeability [Hydraulic Conductivity (K)]	
				(m/sec)	(m/day)
Between Deep Creek and Open Cut 1 and 2 (STX1902A)	774595	7485924	25-35 mbgl (from 4.2 to -5.8 mAHD) [*Kx [Coal Seams & Interburden]*]	1.3 x 10^{-7}	[1.1 x 10^{-2}]
			34-44 mbgl (from -4.8 to -14.8 mAHD) [*Kx [Coal Seams & Interburden]*]	8.7 x 10^{-8}	[7.5 x 10^{-3}]
			43-53 mbgl (from -13.8 to -23.8 mAHD) [*Kx [Coal Seams & Interburden]*]	2.7 x 10^{-8}	[2.3 x 10^{-3}]
			52-62 mbgl (from -22.8 to -32.8 mAHD) [*Kx [Coal Seams & Interburden]*]	2.0 x 10^{-8}	[1.7 x 10^{-3}]
			61-71 mbgl (from -31.8 to -41.8 mAHD) [*Kx [Interburden & Coal Seams]*]	6.0 x 10^{-9}	[5.2 x 10^{-4}]
			70-80 mbgl (from -40.8 to -50.8 mAHD) [*Kx [Coal Seams & Interburden]*]	2.0 x 10^{-8}	[1.7 x 10^{-3}]
			79-89 mbgl (from -49.8 to -59.8 mAHD) [*Kx [Coal Seams & Interburden]*]	2.0 x 10^{-8}	[1.7 x 10^{-3}]
			88-98 mbgl (from -58.8 to -68.8 mAHD) [*Kx [Coal Seams & Interburden]*]	3.3 x 10^{-8}	[2.9 x 10^{-3}]
			25-170 mbgl (from 4.2 to -140.8 mAHD) [*Kx [Coal Seams & Interburden]*]	3.0 x 10^{-8}	[2.6 x 10^{-3}]
			97-170 mbgl (from -67.8 to -140.8 mAHD) [*Kx [Coal Seams & Interburden]*]	1.0 x 10^{-8}	[8.6 x 10^{-4}]
			133-170 mbgl (from -103.8 to -140.8 mAHD) [*Kx [Coal Seams & Interburden]*]	1.1 x 10^{-8}	[9.5 x 10^{-4}]

Source: After AMEC (2019) with additional interpretation/unit conversion in parentheses [].

Based on a review of the packer testing results, and comparison to the relevant geological log intervals and stratigraphic cross-sections (**Section 4.2.2**) it can be reasonably concluded that the interburden intervals tested below and approximately at the base of the Red Seam RL2[25] (i.e. STX1901A at 40-58 mbgl[26] [**Graph 5-8**] and STX1902A at 61-71 mbgl [**Graph 5-9**]) were generally less permeable than the overlying intervals with logged coal seams at approximately 30-40 mbgl.

This supports the groundwater conceptualisation for separation and aggregation of coal seam and interburden intervals to allow application of anisotropy (**Section 6.1.2**).

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[25] Indicative interpolated elevations of -0.2 mAHD and -42.2 mAHD respectively (based on the 2019 geology block model).

[26] Notably, the aquifer testing intervals extended to the base of the drill hole at STX1901A.

5.6.5 Styx Coal Measures (Coal Seams)

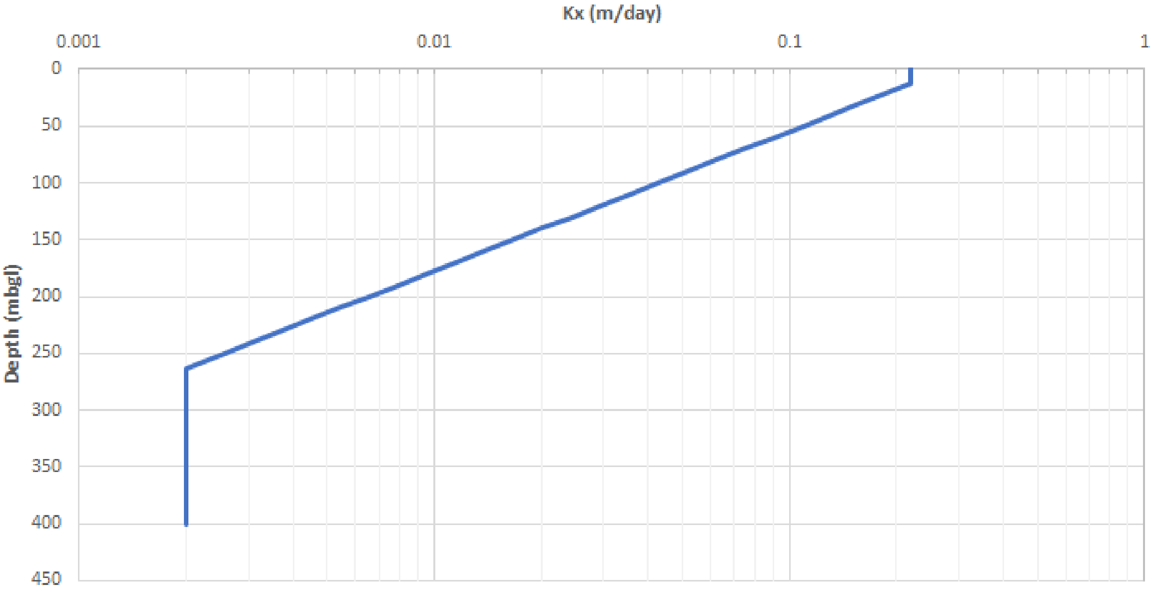
One groundwater monitoring bore (WMP22B) inferred to be targeting the coal seams at the CQC Project by CDM Smith (2018g) was tested for aquifer properties and six aquifer test solutions were determined as follows:

- **WMP22B:**
  - Falling Head Slug Test (Bouwer-Rice Solution): 0.02 m/day (early).
  - Falling Head Slug Test (Bouwer-Rice Solution): 0.01 m/day (late).
  - Rising Head Slug Test (Bouwer-Rice Solution): 0.009 m/day (early).
  - Rising Head Slug Test (Bouwer-Rice Solution): 0.005 m/day (mid).
  - Rising Head Slug Test (Bouwer-Rice Solution): 0.01 m/day (late).
  - Rising Head Airlift Recovery Test (Cooper-Jacob Solution): 0.005 m/day.

The site-specific packer testing in the Styx Coal Measures (overburden and interburden) included coal seam intervals and are presented in **Section 5.6.4**. Notably, packer testing data from many mines in the Bowen Basin was compiled by Coffey (2014) which found that, despite there being a degree of variability due to irregular fracturing, there is a general trend of reducing hydraulic conductivity with depth which is likely due to increasing overburden pressure resulting in reduced fracture aperture.

Hydraulic conductivity of the coal seams was also found to typically be about three times higher (on average) than interburden strata (Coffey, 2014). But it is noted that the hydraulic properties of the coal seams can vary and be influenced by weathering (at the subcrop) and secondary porosity (cleats) in the coal. For example, estimates for coal seam hydraulic conductivity presented by Mackie (2009) in the Upper Hunter Valley of NSW ranged from 1.6 x 10^{-5} m/day to 5.3 m/day, with a mean value of 9.1 x10^{-2} m/day.

Consistent with Coffey (2014) (from field data and testing in the Bowen Basin) and as recommended by the peer review (**Table A2-4**), depth dependence in coal seams has also been considered for the Styx Coal Measures. **Graph 5-12** presents the approach for the application of a linear reduction in hydraulic conductivity (Kx).



Graph 5-12
Depth Dependent Kx Applied in Coal Seams

5.6.6 Styx Coal Measures (Underburden)

Three (3) groundwater monitoring bores inferred to be in the underburden of the Styx Coal Measures at the CQC Project were tested for aquifer properties and seven (7) aquifer test solutions were determined as follows:

- **WMP06:**
    - Falling Head Slug Test (Bouwer-Rice Solution): 0.01 m/day.
- **WMP08D:**
    - Falling Head Slug Test (Bouwer-Rice Solution): 0.03 m/day.
- **WMP22C:**
    - Falling Head Slug Test (Bouwer-Rice Solution): 0.003 m/day.
    - Rising Head Slug Test (Bouwer-Rice Solution): 0.003 m/day (early).
    - Rising Head Slug Test (Bouwer-Rice Solution): 0.002 m/day (mid).
    - Rising Head Slug Test (Bouwer-Rice Solution): 0.003 m/day (late).
    - Rising Head Airlift Recovery Test (Cooper-Jacob Solution): 0.008 m/day.

2019 Aquifer Testing Program (AMEC, 2019)

As described in **Sections 5.6.4 and 5.6.5**, packer testing was conducted and included some intervals including 10 to 15 m of strata below the bottom coal seam to be mined in the proposed open cut. The two bottom intervals in STX1901A and STX1902A, including Styx Coal Measures (Underburden) were respectively comparable with each other.

5.6.7 Back Creek Group (including Boomer Formation)

Six (6) groundwater monitoring bores inferred to be in the Back Creek Group (or Styx Underburden) at the CQC Project by CDM Smith (2018g) were tested for aquifer properties and 23 aquifer test solutions were determined as follows:

- **WMP16:**
    - Falling Head Slug Test (Bouwer-Rice Solution): 0.3 m/day (early).
    - Falling Head Slug Test (Bouwer-Rice Solution): 0.2 m/day (late).
    - Rising Head Slug Test (Bouwer-Rice Solution): 0.2 m/day (early).
    - Rising Head Slug Test (Bouwer-Rice Solution): 0.04 m/day (mid).
    - Rising Head Slug Test (Bouwer-Rice Solution): 0.007 m/day (late).
- **WMP16D:**
    - Falling Head Slug Test (Bouwer-Rice Solution): 0.02 m/day (early).
    - Falling Head Slug Test (Bouwer-Rice Solution): 0.003 m/day (mid).
    - Falling Head Slug Test (Bouwer-Rice Solution): 0.001 m/day (late).
    - Rising Head Slug Test (Bouwer-Rice Solution): 0.01 m/day (early).

  - Rising Head Slug Test (Bouwer-Rice Solution): 0.01 m/day (mid).
  - Rising Head Slug Test (Bouwer-Rice Solution): 0.03 m/day (late).
- **WMP19:**
  - Falling Head Slug Test (Bouwer-Rice Solution): 0.006 m/day.
- **WMP19D:**
  - Falling Head Slug Test (Bouwer-Rice Solution): 0.6 m/day (early).
  - Falling Head Slug Test (Bouwer-Rice Solution): 0.3 m/day (mid/late).
- **WMP20:**
  - Falling Head Slug Test (Bouwer-Rice Solution): 0.1 m/day (early).
  - Falling Head Slug Test (Bouwer-Rice Solution): 0.0004 m/day (late).
  - Rising Head Slug Test (Bouwer-Rice Solution): 0.3 m/day (early).
  - Rising Head Slug Test (Bouwer-Rice Solution): 0.2 m/day (mid).
  - Rising Head Slug Test (Bouwer-Rice Solution): 0.04 m/day (late).
- **WMP20D:**
  - Falling Head Slug Test (Bouwer-Rice Solution): 0.06 m/day (mid).
  - Falling Head Slug Test (Bouwer-Rice Solution): 0.003 m/day (late).
  - Rising Head Slug Test (Bouwer-Rice Solution): 0.09 m/day (early).
  - Rising Head Slug Test (Bouwer-Rice Solution): 0.02 m/day (mid).

Locally, the Arrow Energy N.L. (2007) Well Completion Report at Styx River-2 indicates that an open hole flow test was undertaken for the total depth (365 m) in the Back Creek Group and no water was produced (i.e. gas too small to measure) (**Figure 5-6**).

CDM Smith (2013) presented a summary of hydraulic properties used in previous studies in the Back Creek Group in the Bowen Basin which was augmented by HydroSimulations (2014) and is reproduced in **Table 5-22**.

Further discussion of the Back Creek Group, as part of the Eastern Bowen Coal Measures, is provided in **Section 6.2**.

Table 5-22
Hydraulic Properties Review for the Back Creek Group (After HydroSimulations, 2014)

Stratigraphic Unit	Hydraulic Conductivity		Specific Yield	Specific Storativity	Original Source
	K Horizontal [m/day]	K Vertical [m/day]	S_y [-]	S_s [1/m]	
Back Creek Group	0.01-0.001	0.001-0.00001	0.03-0.18	0.0005-0.000005	URS (2012)
	0.001	0.00001	0.01	0.00001	CDM Smith (2013)

Source: After HydroSimulations (2014) [after CDM Smith (2013)].

5.6.8 Faulting and Groundwater Behaviour

As discussed in **Sections 4.1.4 and 4.1.5**, no significant faults or dykes have been identified by CQCPL's geologists during exploration activities within the CQC Project open cut extent, however a regional fault is mapped at the interface of the Early Cretaceous Styx Coal Measures and Permian Measures of the Bowen Basin east of ML 80187.

Little to no fault activity occurred during the Cenozoic period (Esterle *et al*., 2002; Clarke *et al*. 2011), therefore groundwater behaviour is generally considered unlikely to be affected in such areas. It is however known that faults may limit groundwater flow by vertical displacement of strata (AGE Consultants, 2018). For example, where structure exists between the Early Cretaceous and Permian Measures it may act as a barrier to groundwater flow where, for example, the truncated coal seams (of relative higher permeability) of the Styx Coal Measures meet the lower permeability sequences of the Back Creek Group. This is consistent with the findings in Jourde *et al*. (2002) that faulting can result in lower permeabilities within strata perpendicular to the fault plane, and potentially higher permeability within the strata parallel with the fault plane. However, this can also be dependent on whether faults are currently active (Paul *et al*. 2009). Relevantly, faulting has been inactive within the Bowen Basin for over 140 million years (Clark *et al*. 2011), indicating that the regional faults are less likely to acts as conduits to flow. Kinnon (2010) also assessed the behaviour of faults elsewhere in the Bowen Basin using stable isotope and water quality analysis which showed and supported compartmentalisation due to the structural geology (faulting).

A conceptual model for fault zone hydraulic characterisation in the Bowen Basin was developed by Coffey (2014), based on Jourde *et al*. (2002) and Flodin *et al*. (2001), and has been considered when developing the model geometry (**Section 7.4.2**) and the Uncertainty Analysis (**Section 8.12**).

6.0 CONCEPTUAL GROUNDWATER MODEL, ENVIRONMENTAL VALUES AND WATER QUALITY OBJECTIVES

The simplified hydrogeological units conceptual model is presented schematically on **Figure 6-1** and regional context provided on **Figure 6-2**. The derivation and conceptualisation for groundwater model layers is presented on **Figure 6-3**, and justification in support of the model conceptualisation provided in the following sub-sections. Further to this, specific consideration of the broad conceptualisation for the basement rocks, freshwater-saline water interface (using the Ghyben-Herzberg relationship), as well as preliminary conceptualisation for eco-hydrogeological models (**Figures 6-4[a-b] and 6-5[a-b]**) is provided in **Section 6.3**.

6.1 HYDROGEOLOGICAL UNITS AND GROUNDWATER QUALITY

The following subsection briefly outlines the hydrogeological units and select details relevant to the environmental values and water quality objectives outlined in **Section 6.2** which culminates in the conceptual groundwater model details to inform the numerical groundwater model in **Section 6.3**.

6.1.1 Quaternary and Pleistocene Alluvium / Regolith

The Quaternary and Pleistocene Alluvium / Regolith hydrogeological units are considered to be unconfined aquifers.

Quaternary (Holocene) Alluvium

Consistent with the CQCPL's geologists review conclusions, and supported by the TEM survey findings (Groundwater Imaging, 2019), in conjunction with the review of groundwater levels, soils and geomorphology (Fluvial Systems Pty Ltd, 2020) (**Attachment 6**), the alluvium of the Holocene epoch, relative to the Pleistocene epoch, can be conceptually considered less compacted and of different composition.

The literature review, as well as aquifer testing of hydraulic properties undertaken by CDM Smith (2018g) and AMEC (2019) (**Section 5.6**) both support this hydrogeological concept. Similarly, the results of groundwater quality monitoring demonstrate fresher profiles in WMP05, BH01X and BH16 reflecting potentially more permeable sediments (i.e. higher surface water recharge / infiltration when compared to Qpa units).

Quaternary Pleistocene Alluvium / Regolith

Whilst separation of Quaternary (Holocene) Alluvium is supported (utilising the 1:100,000 Scale mapping with adjustments to reflect localised TEM survey), precise subdivision of the Quaternary Pleistocene Alluvium from the weathered Early Cretaceous is physically less clear at depth (consistent with CQCPL's geologists review), nevertheless for the purposes of analysis the units can be split for application of varying properties to determine (if any) sensitivities during the uncertainty analysis.

This approach is supported by the results of the open end aquifer testing completed by AMEC (2019). The base horizon of weathering [BHWE] (as determined by CQCPL from many drill holes in the 2018 Geological Model) can therefore be used to establish the base of the hydrogeological unit and is generally uniform in thickness across the CQC Project proposed mining areas (average of approximately 22 mbgl).

6.1.2 Styx Coal Measures

The Styx Coal Measures hydrogeological units are considered to be generally confined aquifers, however are expected to be less confined where the coal seams subcrop near the surface / regolith.

Overburden, Coal Seams and Interburden

As discussed in **Section 5.1.2**, recorded groundwater levels (i.e. hydrostatic pressure heads) in several groundwater monitoring bores north of the CQC Project area appear to reflect some (residual) depressurisation at depth, which generally align and correlate with the equivalent seam depths (in liaison with CQCPL's geologists) with historic workings (**Section 3.4.5**), which several decades later may still be undergoing recovery post-mining, including:

- WMP29C[27];
- WMP29D;
- WMP11D; and
- WMP10D (*NB: however appears to be a function of a SWL taken during drilling*).

Nevertheless, based on the available groundwater datasets, hydrostatic pressure heads in groundwater monitoring bores screened in the shallower overburden of the Styx Coal Measures (e.g. WMP10, WMP11 and WMP29B) do not appear to currently reflect clear and discernible water level reductions, nor propagation of such reductions to the surficial Cenozoic deposits and watercourses.

Consistent with Coffey (2014) and as recommended by the peer review (**Table A2-4**), depth dependence in coal seams has been considered for the Styx Coal Measures. **Graph 5-12** presents the approach for the application of a linear reduction in hydraulic conductivity.

Underburden

As described in **Section 5.1.2**, the piezometric pressure head / elevation in the lower stratigraphy (underburden) of the Styx Coal Measures at WMP06 (16.9 mAHD) where it subcrops in the west, and near the pinch / saddle point downstream of the Mamelon Creek and Tooloombah Creek confluence (to the west), Mt Brunswick and Mt Mamelon, and sub-catchment tributary of Tooloombah Creek, is equivalent to the recorded groundwater levels recorded approximately 2.5 km downstream at WMP04. The differences between observed and simulated groundwater levels to the west during the calibration period are considered in **Section 7.7.4**.

6.1.3 Permian Sequence (Back Creek Group, Boomer Formation and Carmila Beds)

The Permian age hydrogeological units are considered to be generally confined aquifers, but again are expected to be less confined where the units subcrop near the surface / regolith.

It is noted that during the development of the Arrow Bowen Gas Project Supplementary Report to the EIS (URS, 2012), the Back Creek Group was separated into a discrete 'deep groundwater system' for the purposes of the supplementary groundwater assessment (Coffey, 2014) to allow separation of direct impacts of the overlying, target coal seams. The CQC Project numerical flow model conceptualisation is consistent with this approach.

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[27] It is however noted that during the construction of WMP29C, the drill hole was developed dry to 59 mbgl, and the deeper hole WMP29D developed dry to 122 mbgl (3 November 2018). Standing water level recorded in November 2019 was also depressed.

Coffey (2014) allocated an overall low sensitivity ranking to the deep groundwater system associated with the Back Creek Group in the Bowen Basin based on the following:

- the groundwater quality within these deep confined aquifers is generally poor, with limited consumptive or productive uses as indicated by low numbers of registered bores;
- limited groundwater yields; and
- the groundwater system would only provide the potential for interaction with GDEs where the water table is sufficiently shallow.

As discussed in **Section 5.6.7**, no water was produced (i.e. gas too small to measure) in an open hole flow test undertaken for the total well depth (365 m) in the Back Creek Group north of the CQC Project.

6.2 ENVIRONMENTAL VALUES AND WATER QUALITY OBJECTIVES

Environmental values (EVs) and water quality objectives (WQOs) for Qld waters are prescribed in Schedule 1 of the *Environmental Protection (Water and Wetland Biodiversity) Policy 2019*. WQOs are long-term goals for water quality management that protect EVs. WQOs are typically based on national water quality guidelines, with a general focus and objective to further characterise and establish appropriate water quality guidelines at a regional and site-specific scale.

The Styx River catchment is part of Basin 127 (Geoscience Australia, 2004) and is generally consistent with the Styx Surface Water Basin (**Section 3.2**).

The environmental values for surface waters and groundwaters specific to the CQC Project are published in the *Styx River, Shoalwater Creek and Water Park Creek Basins Environmental Values and Water Quality Objectives* (DEHP, 2014a) and summarised in **Table 6-1**, with the respective accompanying plans for WQ1271, WQ1272 and WQ1273 shown on **Figures 6-6 and 6-7**.

However, it is noted that the Qld Government published draft consultation materials (including revised EVs, WQOs and aquatic ecosystem protection mapping) (**Figure 6-8**) for the Fitzroy-Capricorn-Curtis Coast Region Groundwaters in early 2019, with the consultation submission closing date on 1 March 2019. Notably, the draft consultation materials recognised Industrial Use as an EV within the Styx Basin.

A summary of the relevant draft EVs are also presented in **Table 6-1**, and discussed further in the following sub-sections. The *Styx River, Shoalwater Creek and Water Park Creek Basins Environmental Values and Water Quality Objectives* (DEHP, 2014a) provides general WQOs for the identified groundwater EVs.

Additional commentary is also available in the draft *Regional Groundwater Chemistry Zones: Fitzroy-Capricorn-Curtis Coast and Burdekin-Haughton-Don Regions Summary and Results* (McNeil *et al*., 2018) for the following Aquifer Class / Chemistry Zones:

- ***Alluvium Zone 6 (Curtis Coast)***

  The Curtis Coast alluvial zone includes Curtis Island, lying just north of the Port of Gladstone and south of the Fitzroy estuary, as well as the relatively small, coastal catchments of Waterpark Creek, Shoalwater, and the Styx River to the north of the estuary. … The water appears suitable for most purposes, although EC and TN may exceed QWQG aquatic ecosystem surface water quality guidelines, and pH (lower range values) may be below the guidelines in places.

Table 6-1
Environmental Values – Surface Waters and Groundwaters for the Styx River Basin and Adjacent Coastal Waters Relevant to the CQC Project

Environmental Value	EP (Water & Wetland Biodiversity) Policy 2019*				Qld Government Draft Consultation Materials (e.g. McNeil *et al.* 2018)			
	Surface Waters	Groundwaters	Estuaries / Bays, Coastal and Marine Waters		Groundwaters [Draft]			
	Surface Fresh Waters – Southern Styx Fresh Waters (including Granite, Tooloombah and Wellington Creeks)	Groundwaters (Bores, etc.)	Styx River, St Lawrence, Waverley and other Creeks (Estuarine Reaches)	Broad Sound	Capricorn Curtis Coast Groundwater – Alluvium	Capricorn Curtis Coast Groundwater – Eastern Weathered Cainozoic Remnants	Capricorn Curtis Coast Groundwater – Eastern Bowen Coal Measures	Capricorn Coast Groundwater Fractured Rock – Eastern Fitzroy Trap Rocks
	WQ1271 **[Figure 6-6]**	WQ1273 **[Figure 6-7]**	WQ1271 **[Figure 6-6]**	WQ1272 **[Figure 6-6]**	GWQ1271 – Draft **[Figure 6-8]**	GWQ1273 – Draft **[Figure 6-8]**	GWQ1279 – Draft **[Figure 6-8]**	GWQ1272 – Draft **[Figure 6-8]**
Aquatic Ecosystems	✓	✓	✓	✓	✓	✓	✓	✓
Irrigation	✓	✓					✓	✓
Farm Supply/ Use	✓	✓	✓					✓
Stock Water	✓	✓	✓				✓	✓
Aquaculture				✓				✓
Human Consumer	✓		✓	✓				
Primary Recreation	✓							
Secondary Recreation	✓		✓	✓				
Visual Recreation	✓		✓	✓				
Drinking Water	✓						✓	✓
Industrial Use							✓	✓
Cultural and Spiritual Value	✓	✓	✓	✓	✓	✓	✓	✓

[1] Rivers, creeks, streams in developed areas (e.g. urban, industrial, rural residential, agriculture, farmlands).

* As discussed in **Section 2.1.3**, the *Environmental Protection (Water and Wetland Biodiversity) Policy 2019* replaced the *Environmental Protection (Water) Policy 2009* on 1 September 2019.

- ***Cainozoic Deposits including Deposits overlying GAB Zone 2 (Eastern Weathered Cainozoic Remnants)***

  Eastern Weathered Cainozoic Deposits has a large area of 33,900 km^2 although it represents only a few samples. It consists of scattered Cainozoic deposits, mainly associated with river channels along the dissected Great Dividing Range from the Bowen to the Boyne. … The water should be tested before giving to stock as there are occurrences of excessive salinity. EC, pH (upper range values) and TN may exceed QWQG aquatic ecosystem surface water quality guidelines.

- ***Earlier Basins Partially Underlying GAB Zone 11 (Eastern Bowen Coal Measures)***

  The Eastern Bowen Coal Measures is a belt of coal bearing sediments extending from the Bowen Basin in the north, through the central Isaac and Mackenzie Catchments, incorporating the Styx and western Fitzroy to the east, and continuing through the upper central Dawson to Castle Creek. The coal bearing sediments are mainly Back Creek Group, underlain by trap rocks, and overlain in the west by Tertiary sediments and weathered to recent alluvium. Bores access members of the coal bearing Back Creek and Blackwater Groups, such as the Boomer Formation, with depths mostly moderate to deep, extending from 15m to 75m. … The water quality is poor for irrigation because sodium levels are excessive for sensitive crops (SAR >8), and EC may exceed irrigation guidelines in some bores. The water should be tested before giving to stock as there are occurrences of excessive salinity. Groundwater EC exceeds QWQG aquatic ecosystem surface water quality guidelines, and TN and pH (upper range values) may do also.

- ***Fractured Rock Zone 10 (Eastern Fitzroy Trap Rocks)***

  The Eastern Fitzroy Trap Rocks are a patch of Palaeozoic volcanics and sediments, including the coal bearing Back Creek Group, lying behind the coast of the in the Lower Fitzroy sub-basin and its watershed with the Dawson sub-basin. … Groundwater EC exceeds QWQG aquatic ecosystem surface water quality guidelines, as TN frequently does, and pH (upper range values) may also.

The Fitzroy and Burdekin Groundwater Chemistry Reports Project Extent and corresponding Fitzroy Basin and Capricorn Curtis Coast Groundwater – Attribution of Bores to Aquifer Class are respectively shown on **Figures 6-9 and 6-10**. As recognised on **Figure 6-9**, the sedimentary Bowen Basin extends across the Fitzroy and Styx Surface Water Basins.

It is noted that in September 2019, the *Great Barrier Reef River Basins End-of-Basin Load Water Quality Objectives* (DES, 2019) was published and derived from the Reef 2050 Water Quality Improvement Plan (Reef 2050 WQIP) targets to help guide licence conditions for environmentally relevant activities that release nutrients or sediment to land or water with the Reef catchment.

Whilst not directly relevant to groundwater, it is noted that the anthropogenic load WQOs to support the Reef aquatic ecosystems EV is targeted at 10 tonnes per year of dissolved inorganic nitrogen (DIN) and 94,000 tonnes per year fine sediments in the Styx Basin by 2025.

6.2.1 Aquatic Ecosystems

There are no known springs or seeps located within the CQC Project disturbance footprint (**Section 5.3**).

As described in **Sections 4.3.1 and 5.4.2 (and Attachment 5)**, Quaternary Alluvium (Qa) sediments are generally associated with Deep Creek and Tooloombah Creek in the vicinity of the CQC Project. Groundwater levels are generally 10-30 mbgl in the Cenozoic sediments and separated from surface waters within the CQC Project disturbance footprint, limiting potential for groundwater to support GDEs and therefore aquatic ecosystems. Aquatic ecosystems associated with surface waters of Deep Creek and Tooloombah Creek are considered separately by Eco Logical Australia Pty Ltd (2020a).

6.2.2 Irrigation

Groundwater is not currently used for irrigation on the Mamelon property. There are no known irrigation bores located in the immediate vicinity of the CQC Project (Table 10-77 in CDM Smith, 2018f). As discussed in **Section 3.4.1**, entitlements exist to support agricultural activities (including irrigation) in the Styx River catchment but are sourced from surface waters.

6.2.3 Farm Supply / Use

Groundwaters are not currently used for farm supply / use within ML 80187 (Table 10-77 in CDM Smith, 2018f), and if used in the past would have been limited due to the generally unsuitable water quality of the Styx Coal Measures and Quaternary Pleistocene Alluvium (**Sections 5.5.2 and 5.5.4**).

Based on a review of the Government database searches, and bore census results (**Section 5.2.3**), a concise list of landholder use bores surrounding ML 80187 is provided in **Attachment 4 (Table A4-2).** Further details are also available in CDM Smith (2018e).

6.2.4 Stock (Drinking) Water

Groundwater resources have and continue to be used for stock watering within ML 80187 and surrounds, with the primary agricultural use being cattle grazing. For the purposes of comparison, the tolerance of livestock to TDS in stock (drinking) water is provided in **Table 6-2**.

Based on the available groundwater quality datasets (**Sections 5.5.2 and 5.5.4**), the groundwaters within ML 80187 associated with the Styx Coal Measures and Quaternary Pleistocene Alluvium are generally unsuitable for stock watering.

Table 6-2
Stock Watering – Tolerance of Livestock to TDS in Stock (Drinking) Water

Livestock	Tolerance Categories		
	No Adverse Effects on Animals Expected	Some Scouring and Initial Reluctance by Animals to Drink, but Stock Should Adapt without Loss of Productivity	Loss of Production and Decline in Animal Condition and Health would be Expected. Stock May Tolerate for Short Periods if Introduced Gradually
Beef Cattle	0-4,000 mg/L	4,000-5,000 mg/L	5,000-10,000 mg/L
Dairy Cattle	0-2,500 mg/L	2,500-4,000 mg/L	4,000-7,000 mg/L
Sheep	0-5,000 mg/L	5,000-10,000 mg/L	10,000-13,000 mg/L^
Horses	0-4,000 mg/L	4,000-6,000 mg/L	6,000-7,000 mg/L
Poultry	0-4,000 mg/L	4,000-6,000 mg/L	6,000-8,000 mg/L
Pigs	0-2,000 mg/L	2,000-3,000 mg/L	3,000-4,000 mg/L

^ Sheep on lush green feed may tolerate up to 13,000 mg/L TDS without loss of condition or production.

WQOs (based on low risk trigger concentrations) are provided for select metal concentrations in livestock (drinking) water and are summarised in **Table 6-3**. Based on the available groundwater quality datasets (**Section 5.5; Tables 5-9; 5-13 and 5-14**), select metal concentrations in groundwaters are generally below the trigger values for stock (drinking) watering.

Table 6-3
Stock Watering – Metal Concentration Low Risk Triggers for Livestock Drinking Water^

Metal	Concentration – Trigger Value (Low Risk)
Aluminium (Al)	5 mg/L
Arsenic (As)	0.5 mg/L (up to 5 mg/L)
Boron (B)	5 mg/L
Cadmium (Cd)	0.01 mg/L
Chromium (Cr)	1 mg/L
Cobalt (Co)	1 mg/L
Copper (Cu)	0.4 mg/L (sheep)
	1 mg/L (cattle)
	5 mg/L (pigs / poultry)
Fluoride (F)	2 mg/L
Lead (Pb)	0.1 mg/L
Mercury (Hg)	0.002 mg/L
Molybdenum (Mo)	0.15 mg/L
Nickel (Ni)	1 mg/L
Selenium (Se)	0.02 mg/L
Uranium (U)	0.2 mg/L
Zinc (Zn)	20 mg/L

^ Higher concentrations may be tolerated in some situations (details provided in AWQG, Volume 3).
Shaded cells = Site-specific metal concentrations are presented in **Tables 5-9, 5-13 and 5-14** for comparison. For other metal concentrations, refer to CDM Smith, 2018f and 2018j).

6.2.5 Aquaculture

Groundwaters are not currently used for aquaculture within ML 80187, nor known to be used for such purposes in proximity to the CQC Project, and therefore is not considered further.

6.2.6 Human Consumer

Based on the relatively poor water quality of groundwaters in the open cut extent and basement rocks within ML 80187 (**Sections 5.5.2, 5.5.4 and 5.5.5**), no groundwaters that report to the sumps within the open cut are anticipated to be suitable for human consumption. It is however noted that some surface waters and associated Quaternary alluvium in nearby watercourses and drainage lines may (at times) meet the ADWG requirements for select parameters.

6.2.7 Primary, Secondary and Visual Recreation

Groundwaters are not currently used for primary, secondary or visual recreation within ML 80187, nor known to be used for such purposes in proximity to the CQC Project. There are no known EVs for primary, secondary and visual recreation, nor any WQOs proposed.

6.2.8 Drinking Water

As described above in **Section 6.2.6**, no groundwaters that report to the sumps within the open cut are anticipated to be suitable for human consumption. It is however noted that some surface waters and associated Quaternary alluvium in nearby watercourses and drainage lines may (at times) meet the ADWG requirements for select parameters.

6.2.9 Industrial Use

The CQC Project would utilise groundwaters that report to the sumps within the open cut in ML 80187. Such groundwaters are anticipated to be of relatively poor water quality (**Sections 5.5.2, 5.5.4 and 5.5.5**) however would be suitable for industrial use and therefore preferentially used in the mine site water balance.

It is noted that groundwaters were used historically for industrial purposes during the operation of the coal mines at Bowman and Ogmore (**Section 3.4.5**). No WQOs are provided for industrial use as water quality requirements for industry vary within and between industries. Similarly, the ANZG Guidelines (2018) (and ANZECC and ARMCANZ [2000]) does not provide guidelines for industry and indicates that industrial water quality requirements need to be considered on a case-by-case basis. Associated groundwaters used by the CQC Project would therefore provide a beneficial industrial use.

6.2.10 Cultural and Spiritual Value

There are no known EVs for cultural or spiritual values within ML 80187, nor known in proximity to the CQC Project. Therefore, potential impacts on such EVs are not considered, nor WQOs proposed**.**

6.3 CONCEPTUAL GROUNDWATER MODEL DETAILS TO INFORM THE NUMERICAL GROUNDWATER MODEL

Consistent with the approach described in Section 10.8.9 of CDM Smith (2018), improvements to the numerical groundwater flow model are undertaken where new data allows a revision and update of the conceptual groundwater model.

The conceptual hydrogeological model is described generally in Section 10.5.6.8 of CDM Smith (2018) and has been reviewed and updated accordingly based on the updates to the regulatory framework and additional data acquired to characterise the hydrological and landscape setting, geology, soils and geomorphology, and groundwater datasets and dependent assets (including groundwater connectivity and dependence) (**Sections 2.0 to 5.0,** and **Sections 6.1 and 6.2**).

Based on review of all of the above, and generally consistent with the four (4) Aquifer Class / Chemistry Zones in the draft *Regional Groundwater Chemistry Zones: Fitzroy-Capricorn-Curtis Coast and Burdekin-Haughton-Don Regions Summary and Results* (McNeil *et al*., 2018), the data supports four conceptual groundwater systems as follows:

- **Alluvial (Holocene) Groundwater System** – including alluvial (narrow-channel) sediments within the deep cut infills of Tooloombah Creek and Deep Creek as well as estuarine sediments toward the Styx River mouth downstream of the CQC Project.
- **Alluvial (Pleistocene) Groundwater System –** including Cenozoic sediments (beyond the Holocene alluvial sediments) overlying the Early Cretaceous Styx Coal Measures however, precise subdivision of the Quaternary Pleistocene Alluvium from the weathered Early Cretaceous (i.e. regolith of the sedimentary rocks) is physically less clear at depth.

- **Sedimentary Rock Groundwater System** – including the shallow rock Early Cretaceous Styx Coal Measures, including relatively higher permeability coal seams/plies, albeit reducing permeability with depth.
- **Sedimentary and Fractured (Basement) Rock Groundwater Systems** – including shallow and deep rock groundwater bearing structures and the Permian Measures of the Back Creek Group to Carmila Beds and Lizzie Creek Volcanic Group to Connors Volcanic Group.

The simplified hydrogeological units conceptual model is presented schematically on **Figure 6-1**. As discussed in **Section 4.3.1**, the refined 1:100,000 Scale mapping (**Figure 4-3**) has been used with adjustments to reflect localised TEM survey in support of separation of the Holocene and Pleistocene units.

Recognising the conceptual and numerical groundwater model developed in CDM Smith (2018), the conceptual groundwater model layers and initial hydraulic parameter targets have been determined and used for the purposes of the numerical groundwater model design, construct and calibration in **Section 7.0**. Relative comparisons are annotated within the **Table 6-4** in **green** (increased) and **red** (decreased) to identify the changes to the conceptual groundwater model.

6.3.1 Broad Conceptualisation for Basement Rock

The conceptual cross-section of the basement rock is presented on **Figure 6-1**, based on interpretation of available geological mapping (**Section 4.2**) and cross-sections (**Figures 4-2[b], 4-3[b], 4-3[c] and 4-6[b]**, available drill logs and consultation with CQCPL's geologists.

Reference is made to the mapped structure / fault in the basement rock at the interface of the Early Cretaceous Styx Coal Measures and Permian Measures to the east/north-east of the CQC Project. Further discussion on how the structure has been represented and considered in the numerical groundwater model is provided in **Section 7.4.2 and 8.12.1**.

6.3.2 Broad Conceptualisation for Freshwater-Saline Water Interface (Ghyben-Herzberg Relationship)

The location of the steady state interface between oceanic saltwater and inland (fresher) groundwaters can be conceptually based on the generalisation that discharge of inland fresh water is maintained toward the ocean (Verruijt, A., 1968) and the Ghyben-Herzberg Relationship used to relate the depth of the interface below sea level to the height of the free groundwater surface by the following formula (**Figure 6-11**):

$$\boldsymbol{h_f = \alpha h_s}$$

where
h_f = height of free groundwater above sea level;
h_s = depth of seawater interface below sea level; and
$\alpha = (\rho_s - \rho_f)/\rho_f$
and
ρ_f = freshwater density (1.000 gm/cc); and
ρ_s = saltwater density (1.025 gm/cc).

Thus, applying the relationship at the Ogmore Road Bridge (several kilometres downstream of the CQC Project) and assuming approximately 1-2 m of freshwater head (assuming average – static conditions above the long term mean sea level), the theoretical depth of the seawater interface would be expected to be at approximately 40-80 m. Considering the inferred groundwater level (phreatic surface) further inland at the Tooloombah Creek and Deep Creek confluence (north of the CQC Project) is up to 10 m (i.e. h_f = 7 m), it would then equate to a 280 m interface depth. Furthermore, noting that the SWL at the deepest northern extent of the proposed open cut is in the order to 15-20 mAHD (**Figure 5-3**), it would then equate to a 480-680 m interface depth. For relative comparison, the bottom of the proposed open cut at the deepest point is at approximately -152 mAHD.

Table 6-4
Conceptual Groundwater Model Layers and Initial Hydraulic Parameter Targets

Model Layer		Hydraulic Conductivity		Specific Yield	Specific Storativity
		$K_{Horizontal}$ [m/day]	$K_{Vertical}$ [m/day]	S_y [-]	S_s [1/m]
1	Styx Coal Measures Overburden / Interburden (Out-of-Pit Emplacement Final Landform)	1[#]	0.1	0.005	0.000005
2– 3	Qa, Qhe/s, Qhe/m, Qhcm	10 **(x2~)**	0.41	0.02 **(x2)**	0.000013[+] (**x2~**)
	Qpa, Qr, Qf > Kx	4.1	0.41	0.01	0.000013[+] (**x2~**)
	Regolith / Weathered Kx, Pb, Pbm, Pc	1	0.1	0.005	0.000013[+] (**x2~**)
	TQr, Ta, Td	**1**	**0.1**	**0.01**	**0.000013[+]**
4	Regolith / Weathered Kx, Pb, Pbm, Pc, Cp	1	0.1	0.005	0.000013[+] (**x2~**)
5	Styx Coal Measures (Overburden / Interburden – Upper)	0.02	0.002 (**÷10**)	0.005	0.000005
6	Coal (G1-R Lower Aggregate)	0.22-0.002* (Up to **x70**)	0.075 (**x25**)	0.005	0.000005
7	Styx Coal Measures (Interburden – Mid)	0.003	0.0015 (**÷2**)	0.005	0.000005
8	Coal (P-B Lower 2 Aggregate)	0.22-0.002* (Up to **x70**)	0.075 (**x25**)	0.005	0.000005
9	Styx Coal Measures (Interburden – Lower)	0.003	0.0015 (**÷2**)	0.005	0.000005
10	Coal (V Upper 1-V Lower 2 Aggregate)	0.22-0.002* (Up to **x70**)	0.03 (**x10**)	0.005	0.000005
11	Styx Coal Measures (Underburden)	0.004	0.002 (**÷2**)	0.005	0.000005
12	Back Creek Group / Boomer Formation	0.004 (**x10**)	0.002 (**÷2**)	0.005	0.000005
	Glenprairie / Wangrabry Beds	0.0004	0.0002 (**÷2**)	0.005	0.000005
13	Lizzie Creek Volcanic Group / Carmila Beds	0.0004	0.0002 (**÷2**)	0.005	0.000005
14	Intrusive Rocks / Connors Volcanic Group	0.00001	0.00001	0.005	0.000005

* It is known in Eastern Australian coal basins that seam permeability typically reduces with depth. A depth dependent (horizontal) hydraulic conductivity (K_H) linear reduction has been applied with a lower bound capped to no more than two orders of magnitude lower than the upper bound value, at the deepest point of the open cut.

^ Where the depth dependent K_H is reduced to be equivalent to K_V, it has also been reduced accordingly, at a ratio of 2:1 to ensure $K_H > K_V$.

[+] Application of physical upper limit for unconsolidated materials as determined by Rau *et al*. (2018).

[#] Based on Hawkins (1998).

However, it is relevantly noted that this conceptualisation assumes the density of freshwater is maintained inland, and it is known the Cenozoic sediments tend to be brackish to saline (**Section 5.5.2**), so conservatively applying a lesser differential, and a reduced (half) α factor (where ρ_f ~1.012 gm/cc), the interface would still be in excess of 500 m for a height of free groundwater above sea level of 6.5 m. It is recognised that there are many other factors which effect the interface location including topography, geology architecture (geometry), recharge, vegetation cover as well as historic anthropogenic use. Each of these factors are considered by the improved numerical groundwater model.

Review of the available groundwater quality datasets at WMP29A to WMP29E shows that the salinity ranges (at various depths as TDS; and EC) are as follows (**Figure 5-1[b]**):

- WMP29A (12.5 mbgl) = 5,760 mg/L; 8,849 μS/cm (80th%ile);
- WMP29B (20.0 mbgl) = 14,400-15,700 mg/L; 22,700 μS/cm (80th%ile);
- WMP29C (58.0 mbgl) = 11,600-12,000 mg/L; 20,560 μS/cm (80th%ile);
- WMP29D (121.0 mbgl) = 11,800-13,100 mg/L; 19,900 μS/cm (80th%ile); and
- WMP29E (228.5 mbgl) = 5,410-6,140 mg/L; 19,370 μS/cm (80th%ile).

It is also relevantly noted that only the following groundwater monitoring locations have recorded TDS concentrations in excess of 35,000 mg/L (i.e. salinity equivalent to seawater) (**Figures 5-1[a] and 5-1[b]**):

- WMP13 (*screened at and immediately below 0 mAHD, downstream of the CQC Project at Ogmore*) TDS = 22,300-41,200 mg/L; EC = 48,460 μS/cm (80th%ile); and
- WMP26 (*but is screened above 7 mAHD*) TDS = 34,000-37,300 mg/L; EC = 47,353 μS/cm (80th%ile).

Landholder Bore 67654 (BH25) (**Figure 5-2**) near the Broad Sound Fish Habitat Area (FHA-047) also includes historic groundwater quality measurements taken in 1992 and 2002 which respectively recorded at 7 m depth (at and below 0 mAHD) an EC of 11,620 μS/cm (27 November 1992) and 40,600 μS/cm (18 December 2002).

Measured groundwater pressures at depth at WMP29D at -8 mAHD (below sea level) potentially as an effect of historic mining downgradient of the CQC Project area may still be in recovery (at depth) thus conditions remain transient north of the historic Ogmore workings. However, groundwater levels (and quality) in the shallower groundwater monitoring bores (WMP29A and WMP29B) remain at and/or above long term mean sea levels (**Section 3.3**) and as noted above remain relatively fresh by comparison.

That is, based on a review of the available groundwater quality datasets, there is no idealistic freshwater-saline groundwater interface evident, which is not unexpected given the geological and geomorphological history as outlined in **Section 4.6.1**. Further analysis and discussion regarding historic mining are provided in **Sections 7.5.6 and 8.10**, but importantly, as presented in **Section 8.5.1**, the predicted groundwater drawdown (i.e. 1-2 m contours) influence in the Styx Coal Measures as a result of the CQC Project do not extend as far as the historic Ogmore mine workings (some 8 km downstream) to result in any superposition effects, and therefore is not expected to result in any discernible change to the location of the conceptual freshwater-saltwater interface. That is, even if the conceptual interface was to be transient (or static) north of the historic Ogmore workings, there would not be expected to be any discernible change due to the CQC Project alone.

Further to the above, consideration of corrections of coastal heads in the numerical groundwater model is discussed separately in **Section 7.5**.

6.3.3 Preliminary Conceptualisation for Eco-Hydrogeological Models

A preliminary eco-hydrogeological conceptual model is presented in **Figures 6-4[a] & [b]{i-iv]**, based on a cross-section at the pinch/saddle point between Mt Brunswick and Mt Mamelon across Tooloombah Creek. The topography shown is based on available elevation datasets, the groundwater level shown based on the nearby groundwater table recorded at WMP06, and lithology based on the 1:100,000 scale outcrop geology mapping. The conceptual flood elevations also recognise the model generated surface water levels in Tooloombah Creek by WRM Water & Environment (2020) are in the order of approximately 25 mAHD and above for the 10% AEP design event (for existing conditions) along Tooloombah Creek in the vicinity of the CQC Project at WMP06 (**Section 3.3.3**).

The vegetation root depth concepts are generally based on Canadell *et al*. (1996) as well as similar concepts presented in Jones *et al*. (2019).

Hydrological (interflow) concepts are shown based on the flow duration curves developed by WRM Water & Environment (2020) (**Sections 3.3.3 and 3.3.4**) however it is recognised that other factors (e.g. downstream rock bar control, and the potential for upstream bottlenecking/storage of flows prior to discharge at the Tooloombah Creek and Mamelon Creek confluence in the unconsolidated alluvial sediments) may result in extended interflow/pool persistence within the downstream reach of Tooloombah Creek.

Further consideration and analysis is provided separately by Eco Logical Australia Pty Ltd (2020d), recognising the different mechanisms of surface water and groundwater interactions previously outlined in Figure 9-26 of CDM Smith (2018h). It is important to note the following when considering the preliminary eco-hydrogeological conceptual model presented in **Figures 6-4[a] & [b]{i-iv]**:

- **Interflow** occurs when infiltrating surface and subsurface flow above the regional groundwater table is diverted towards a watercourse channel bed (or downgradient within the channel bed) by stratigraphic changes. The quantum is driven by hydrological (surface water) processes, which is determined in the AWBM (**Section 3.3.3**) by what is called a baseflow index (BFI) for runoff that is estimated to become baseflow (or interflow) and a baseflow recession constant (Kb) that determines the rate at which the baseflow (or interflow) is discharged from the baseflow storage. The AWBM baseflow (or interflow) must not be confused with the groundwater baseflow definition as follows.
- **Baseflow** occurs when the elevation of the regional groundwater table proximate to the watercourse channel bed exceeds the surface water level.

It is recognised that seasonal and extended dry conditions may control the saturated water elevation and thus the direction of flow between a watercourse and aquifer at different points in space and time. For example, when the hydraulic gradient of the aquifer is toward[28] the watercourse, the stream may be considered gaining, and conversely, if the hydraulic gradient of the aquifer is away from the watercourse, the stream may be considered losing.

Depending on the season/period under investigation, the channel system can be hydraulically connected to the aquifer or have a leaking streambed through which water can infiltrate to the subsurface. The extent of this interaction depends on physical characteristics of the channel system and channel bed composition (e.g. streams commonly contain a silt layer in the bed which reduces conductivity between the stream and the aquifer). This mechanism is explicitly considered in the numerical groundwater model and discussed in **Section 7.5.3**.

Conceptual cross-sections at Wetlands 1 and 2 based on the available observation records and groundwater monitoring datasets in **Sections 5.1.4 and 5.3.2** are also shown on **Figure 6-5[a&b]**.

6.3.4 Baseline Conditions

Based on the information presented in **Sections 2.0 to 5.0** (and **Sections 6.1 and 6.2**) and with reference to the simplified hydrogeological units conceptual model (**Figure 6-1**), the following baseline characteristics are relevantly noted:

- Diffuse rainfall recharge occurs across the Styx River catchment at varying rates with higher recharge expected where less consolidated Cenozoic sediments (i.e. Quaternary Alluvium) is present, as opposed to Quaternary Pleistocene Alluvium, and less again for Tertiary and weathered regolith (i.e. outcropping Early Cretaceous, Permian and Volcanic basement rocks). Average annual rainfall is approximately 715 mm/year.

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[28] Considering the relevant longitudinal and lateral flow vector magnitude and directions.

- Flood recharge events occur during large and sustained streamflow events and are expected to result in the highest rates of recharge, albeit episodic. As noted on **Graph 3-2**, three separate flood recharge events have been recorded since 2010 (2010-11, 2013 and 2017), with approximately 65%-75% of annual average rainfall occurring during one month of the year.

- While annual pan evaporation rates are in often excess of 2,000 mm/year (**Table 3-1**), the average areal actual evapotranspiration (annual) for the CQC Project and surrounds is estimated to be approximately 715 mm/year (**Figure 3-3**), generally equivalent to the recorded average rainfall.

- Clay is the most frequently encountered material within the Quaternary age sediment across the CQC Project area (i.e. Quaternary Pleistocene Alluvium) and is consistent with the findings of the TEM survey and observations of CQCPL's geologists, whereby more permeable 'Holocene' alluvium is restricted to rare deep cut infills and that no levees banks have formed along the watercourse margins (indicating overbank flooding [e.g. deposition beyond the channel] is rare). Refer to **Section 7.4.1** for further discussion of the groundwater model layer conceptualisation.

- When considering that besides surface water entitlements and the few existing stock watering bores used by landholders which are generally associated with Quaternary alluvium adjacent the watercourses, the Styx Coal Measures do not appear capable of producing significant quantities of useable groundwater and is generally of poor quality. Furthermore, searches of the Government databases demonstrate that more broadly in the Styx River catchment, groundwater users are in the Permian Measures and/or Volcanic units which are generally not as poor a water quality as the Styx Coal Measures.

- Although the shallow groundwater levels in the surficial sediments and outcropping rock units are sustained by rainfall infiltration (as demonstrated in **Attachment 8**, several hydrographs show declining groundwater levels during the extended below average rainfall conditions experienced since 2017), they are controlled by topography, geology and surface water levels in local drainages (i.e. localised leakage). Local groundwater tends to mound beneath the hills to the west (**Figure 5-3**), with ultimate discharge to local drainages and/or loss by evapotranspiration through geological outcrops and vegetation where the unconfined water table is nearer to the ground surface in lower-lying/incised areas (**Figure 5-4**).

- Whilst the coal seams of the Styx Coal Measures are expected to be more permeable than the surrounding overburden/interburden, they are not highly transmissive due to the aggregated seam/ply thicknesses being in the order of metres spread across the mining interval. This is consistent with the findings of the localised packer testing by AMEC (2019) (**Attachment 7**).

- Local faults may act as permeable or conductive features, but more likely as barriers to flow (e.g. where coal seams abut the less permeable basement rock units). For the purposes of this assessment and conservatism, faulting is not assumed to be a no flow barrier.

- Given the recent extended period of dry (and no flow) conditions recorded in many of the local drainages, rainfall runoff is likely to be the primary source of stream flow across the CQC Project area.

- As demonstrated by the various investigations (**Sections 3.5, 5.1.4 and 5.3.2**), wetlands in the vicinity of the CQC Project are unlikely to be dependent on or connected to the regional groundwater table (measured at 10 mbgl and greater [**Table 5-6; Figure 6-5[a&b]**]). The wetland systems are considered to exist due to the presence of clays in the shallow subsurface of the Cenozoic sediments and localised topographic undulations, which allow perched water tables / moisture profiles to develop and persist after rainfall events (**Plate 3-18**).

As discussed in **Section 3.4.5**, recovery over several decades post-mining at the historic mine workings at Bowman and Ogmore is expected to be ongoing (i.e. transient) and therefore should be considered as such.

6.3.5 During Mining Conditions

During mining, the potentiometric heads in the sedimentary rock groundwater system would be reduced in the vicinity of the open cut mine extents where the Styx Coal Measures are targeted (**Figure 6-1**), but the localised water table may rise beneath above-ground and in-pit backfilled waste rock emplacement mounds (due to enhanced localised recharge in excavated spoil). Some localised dewatering of the Cenozoic sediments (albeit negligible/dry in near surface areas) where excavated within the open cut extent could occur initially (resulting in short-term groundwater inflows).

Drawdowns within the coal measures would occur immediately around the active open cut excavations where the Styx Coal Measures are targeted (**Figure 6-1**). Some upflow from the permeable coal measures may be experienced initially (albeit reduced due to the historic mine workings) however would be expected to gradually reduce over time. Up-dip coal seams of the Styx Coal Measures which are not mined, are also expected to receive some enhanced rainfall recharge where they subcrop or outcrop in the west / south-west (**Figure 6-1**).

Drawdown would tend to propagate along the strike of the mined coal seams of the Styx Coal Measures (i.e. north-west to south-east), rather than west (where the coal measures are absent and the Back Creek Group outcrops), north/north-east (where the coal measures increasingly deepen with intervening overburden/interburden with reduced permeability) or further east (where the coal seams abut the less permeable basement rock units).

Groundwater sourced from the coal measures and/or via enhanced recharge would report to the open cut sumps as groundwater inflows. However, it is noted that the actual volume of groundwater inflow observed or requiring direct management may be significantly less where higher evaporation rates were to occur at the highwalls and floor of the open cut mining operation.

6.3.6 Post Mine Closure Conditions

The open cut voids would be backfilled during mine closure and is discussed in **Section 8.3.6**.

Until the voids are backfilled to the pre-mine groundwater table and re-saturated, the backfilled open cut would continue to draw in groundwater (at a reducing rate) from the surrounding geological units (predominantly the Styx Coal Measures). Enhanced (fresher) rainfall recharge (and evapotranspiration) in backfilled spoil and localised watertable rise beneath final landforms could be expected to maintain a localised groundwater sink for several decades and beyond within the extent of the open cut at the CQC Project.

6.3.7 Conceptual Model Balance

A conceptual model balance is a simplification of the inputs and outputs to the groundwater system(s) to assist in understanding the potential impacts of a development in a regional context. An undeveloped groundwater basin (i.e. no change in storage) exists in a state of approximate equilibrium that balances groundwater recharge and discharge processes, and the flows between formations are in steady-state (Coffey, 2014).

As described in **Section 3.1.2**, the average areal actual evapotranspiration (annual) for the CQC Project and surrounds is estimated to be approximately 715 mm/year (**Figure 3-3**) and is generally equivalent to the recorded average rainfall.

CDM Smith (2018f) presented the steady state groundwater recharge input rate within the previous model domain to be in the order of 5.4 GL/annum (14.7 ML/day), which when compared to the conservatively predicted cumulative abstraction volume over the 18 year mine life (on an average annualised basis) is approximately 5.7%.

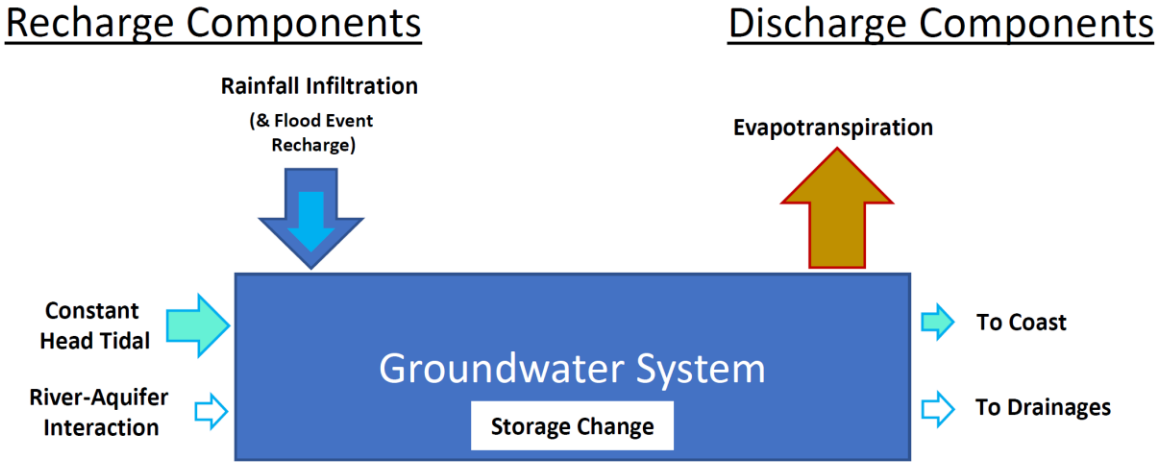
The evapotranspiration rate presented in CDM Smith (2018f) for the steady state calibrated model was -10.8 ML/day (approximately 74% of all model outputs).

However, within the Styx Basin, historic mine workings in the Styx Coalfield from the 1920s to 1960s has resulted in a change in the groundwater basin equilibrium (and storage) and consequential transient recovery processes at depth which are expected to continue for several decades. This process itself can lead to increased groundwater recharge rates because of the increased hydraulic gradients resulting from historic drawdown. And whilst anthropogenic groundwater use in the area is considered relatively minimal due to poorer groundwater quality associated with Early Cretaceous and Permian measures, as well as generally low-yielding formations, groundwater extraction by landholders also has a notional deficit effect on total groundwater storage, until a new steady-state is reached.

That is, it is considered that such declines in groundwater storage by historic and present anthropogenic use, and future uses including the CQC Project, would be balanced (in most part) by changes to throughflow or enhanced recharge and therefore declines in total groundwater storage temporary in nature until a new steady-state is reached.

As discussed in **Section 6.3.4**, local groundwater tends to mound beneath the hills to the west (**Figure 5-3**), with ultimate discharge to local drainages and eventually to the coast.

Thus, the simplified conceptual model balance is illustrated as follows in **Flowchart 6-1**.



Flowchart 6-1
Simplified Conceptual Model Balance Components

7.0 NUMERICAL GROUNDWATER MODEL – DESIGN, CONSTRUCT AND CALIBRATION

7.1 APPROACH TO NUMERICAL GROUNDWATER FLOW MODELLING

7.1.1 Previous Numerical Groundwater Flow Models (CDM Smith, 2017; 2018e)

Details of the previous numerical groundwater models are presented in detail in:

- *Central Queensland Coal Project Groundwater Technical Report* (CDM Smith, 2017).
- *Central Queensland Coal Project Appendix A6 – Groundwater Technical Report* (CDM Smith, 2018e).

Key attributes of the CDM Smith (2018e) numerical groundwater model are outlined in **Table 7-1**.

Chronology of Consultation / Engagement with Regulatory Agencies

From the submission of the application to prepare an EIS for the CQC Project on 16 December 2016 through to the conceptualisation and initial assessment of impacts and risks, to the modelling investigations and quantitative and qualitative uncertainty analysis to date, engagement with key regulatory agencies has occurred, and feedback sought during consultation (i.e. draft TOR development, EIS exhibition, SEIS review and IESC advice) for consideration. The government submissions relevant to **this Report** and IESC advice received during the course of prior assessments and consultation are outlined in **Attachment 1**.

More recently, on 20 November 2019 and 28 February 2020, details of the improvements to the numerical groundwater modelling and uncertainty analysis methodologies (**Section 7.1.3**) proposed by HydroAlgorithmics to improve the confidence in model predictions were presented and discussed with the DES, outlining the combination of statistical methods available and scenario-based analyses proposed. A copy of the slides presented during the DES briefings are provided in **Attachment 17**.

7.1.2 CQC Project Numerical Groundwater Flow Model with Improvements (CQC-LF3)

For the purposes of comparison, key attributes of the previous CDM Smith (2018e) model are provided in **Table 7-1** to demonstrate the improvements made to the numerical groundwater model.

These improvements were also made cognisant of the evolution and ongoing improvements made recently by the OGIA to enhance the understanding of groundwater flow systems for the prediction of impacts elsewhere in Qld coal basins (i.e. Surat Basin, and parts of the Bowen and Clarence Moreton Basins) documented in *Underground Water Impact Report for the Surat Cumulative Management Area – July 2019* (DNRME, 2019).

7.1.3 Uncertainty Analysis Methodologies

On 20 November 2019 and 28 February 2020, details of the uncertainty analysis methodologies proposed by HydroAlgorithmics were presented and discussed with the DES, outlining the combination of statistical methods and scenario-based analyses initially proposed, including a preliminary list of relevant parameterisations for investigation and/or analysis:

- [I] Tidal Boundary Condition Range (incorporating Sea Level Rise Predictions).
- [II] Rainfall Recharge Totals (incorporating Climate Change Scenario Range and Adopted Alluvium / Regolith (%) Recharge).

Table 7-1
Proposed Improvements to the Numerical Groundwater Model[#]

Attribute	CDM Smith (2018)	CQC-LF3 Groundwater Model (2020)	Description of Improvements
Model Domain / Dimensions	43 km x 54 km.	57 km x 54 km.	**Model Extensions**: to the north-east to include greater portion of Broad Sound FHA-047, existing tidal monitoring point and envelope Wellington Creek (including Stoodleigh Creek) Catchments; and to the north-west to envelope the Granite Creek catchment.
Model Layers / Properties	6 Layers (Combined Quaternary Units, Combined Coal Seams and Interburden) + Basement.	14 Layers + Basement.	**Separation and Aggregation**: of model layers (for coal seams) to separate interburden and application of anisotropy*, supported by laboratory core permeability testwork, and investigation of historic mine workings groundwater levels/pressures. **Partitioning**: of Qa / Qhe from Qpa / Qf / Regolith units in upper layers in model to allow for refined groundwater connectivity analysis, based on available geology mapping, fluvial geomorphology descriptions and localised refinements (based on TEM survey), supported by available groundwater level and quality datasets.
Model Geometry and Mesh Design	Structured grid (0.47 million active cells), ranging from 20-640m. [Coarse to Very Fine]	Unstructured grid (0.49 million active cells). [Coarse to Fine]	**Refinement:** of model grid (unstructured) along watercourses, drainage features and wetlands for groundwater connectivity analysis, as well as inclusion of historic mine workings, and location of geological structure (regional faults). **Delineation:** of Qa and Qpa / Regolith units, based on available geology mapping, fluvial geomorphology descriptions and localised refinements (based on TEM survey)[+]. Fault position consistent with 1:100,000 scale mapping and local interpretation by CQCPL's geologists.
Structure / Faults	No.	Included in model geometry as above.	**Analysis:** to allow zones of [enhanced or reduced] hydraulic conductivity to be considered in Uncertainty (Sensitivity) Analysis.^
Model Boundary Conditions	No flow along topographic ridges of Styx River catchment. Tidal constant head boundary condition applied (2 mAHD).	No flow along topographic ridges of Styx River catchment. Tidal constant head boundary condition applied (e.g. 3.5 mAHD) and sensitivity range (2 mAHD-4.5 mAHD).	**Model Extensions:** No flow boundary conditions extended along topographic ridges for whole of catchment. **Refinement:** Application of higher tidal constant head boundary condition supported by analysis of tidal gauges in the Broad Sound (McEwin Islet and Stanage) and long term coastal Port records north (Hay Point) and south (Rosslyn Bay), including comparison to WMP29A datasets, and consideration of correction factor for seawater density.^ **Delineation:** Conservative application of tidal constant head boundary condition along mapped estuarine reach of the Styx River (i.e. to Ogmore Road Bridge).
Model Drains	Drains applied to Styx River, Tooloombah, Sarsfield, Mamelon, Deep, Brussels and Wellington Creek.	As per CDM Smith (2018) with additional drains.	**Additional Coverage:** of drains applied to Granite Creek, Montrose Creek, Barrack Creek, Brumby Creek, Kyour Creek, Oaky Creek, Magdelan Creek, Gilnorchie Creek, Clive Gully, Tooloombah Creek South Branch, Tooloombah Creek North Branch, Stoodleigh Creek, Ewan Creek, Oaky Creek, Landsborough Creek, Wangraby Creek and Stotts Creek.

Table 7-1 (Continued)
Proposed Improvements to the Numerical Groundwater Model[#]

Attribute	CDM Smith (2018)	CQC-LF3 Groundwater Model (2020)	Description of Improvements
Spatial Parameter Variability	No.	Yes. (ET Extinction Depths and Maximum Rates [Geology/Vegetation], Cenozoic Sediments [Horizontal Permeability based on Partitioning]).	**Refinement:** Application of ET extinction depths based on maximum rooting depths of vegetation types (considering Canadell *et al*, 1996 and Shah *et al*., 2007) and actual ET applied as corresponding maximum rate. **Partitioning:** As above for Qa / Qhe and Qpa / Qf / Regolith units.
Steady State Calibration	Yes.	Yes.	-
Calibration Period	Jan 2017-Mar 2018 (15 months) [1.25 Years]	Jan 2011-Sep 2019 [8.75 Years with refined 33 month period]. [*NB: ~100 Years Initial Conditions for Historic Mines*]	**Extension:** of calibration period to include available datasets collected in 2011-12 & 2014, additional data collected since March 2018, and consideration of ~40 years of historic mining and ~60 years of recovery.
Prediction Period	18 Years + 1 Year Backfill	18 Years.	**Refinement:** generally consistent with Styx Dumps (excluding final rehabilitation) presentation (Alpha-Mine Planning 4U (29 Sep 2018), to present maximum predicted drawdown extents.
Prediction Period Temporal Discretisation	One month stress period length with 7-12 day timesteps.	Generally consistent with calibration scale.	**Application:** of stress period length and timesteps during mining to be consistent with calibration scale.
Temporal Parameter Variability	No.	Yes (Spoil in Backfilled Void).	**Application:** of TVM Package to model backfilled spoil.*^
Backfilled Spoil Properties	Retained host properties in backfilled spoil.	Apply time-varying properties to backfilled spoil.	**Application:** As above.
Recovery Period	500 Years.	1 Year Backfill + 100-500 Years.	**Refinement:** generally consistent with Styx Dumps (final rehabilitation) presentation (Alpha-Mine Planning 4U (29 Sep 2018), to present post-mining (complete backfilled) final landform groundwater levels.
Fate Seepage / Solute Transport Modelling or Alternative	No.	Yes [Simplified Alternative]	**Application:** to present changes in flow directions / gradients post-mining. Simplified approach subject to review based on predictive model outcomes.
Cumulative Assessment	No.	Yes.	**Refinement:** of model geometry to include historic mine workings (digitised by CQCPL) to allow historic depressurisation (and recovery) in coal seams at depth.
Representation of Past (Historic) Workings	No.	Yes. Conservative extents in representative coal seam layers only.	
Sensitivity Analysis	Yes	Yes. With Identifiability Analysis.	**Contemporary Application:** of Identifiability Analysis guided by IESC's *Information Guidelines Explanatory Note: Uncertainty Analysis – Guidance for Groundwater Modelling within a Risk Management Framework* (dated 17 December 2018).

Table 7-1 (Continued)
Proposed Improvements to the Numerical Groundwater Model[#]

Attribute	CDM Smith (2018)	CQC-LF3 Groundwater Model (2020)	Description of Improvements
Uncertainty Analysis	Yes.	Yes.	**Contemporary Analysis:** to increase robustness of Uncertainty Analysis guided by IESC's *Information Guidelines Explanatory Note: Uncertainty Analysis – Guidance for Groundwater Modelling within a Risk Management Framework* (dated 17 December 2018).
Mitigation Measures / Recommendations	Yes.	Yes.	**Refinement:** to reflect improved numerical groundwater model predictions/outcomes and address relevant matters raised in Government agency responses.
Future Monitoring (Reference and Compliance) and Adaptive Program Investigations	Yes (Reference and Compliance Only).	Yes.	**Justification**: of future monitoring to reflect improved numerical groundwater model predictions/outcomes, allow adaptive management and address relevant matters raised in Government agency responses
Outputs	Groundwater Inflow Estimates / Significant Impact Focus	As per CDM Smith (2018), with Spatial and Time Series Plots	**Reporting:** to allow presentation of impact prediction plots and supporting tables.
Licensing Volume Estimates	Indicative.	Indicative, with Firm Recommendations.	**Reporting:** to align with EP Act s126A and Water Act 2000 Requirements.
Reporting	Substantial	Substantial, yet Condensed and Focussed on Matters of Significance	**Reporting:** for ease of reconciliation of matters raised in Government responses.

* Consistent with HydroAlgorithmics Peer Review comments (6 January 2019) [**Attachment 2; Table A2-2**].

^ Consistent with AGE Peer Review comments (5 February 2019) [**Attachment 2; Table A2-3**].

[#] The proposed improvements were subject to ongoing review and refinement during the groundwater model build and calibration, and will continue to be during subsequent phases by HydroAlgorithmics, and therefore subject to change.

[+] Delineation of alluvium also generally consistent with the draft consultation materials published in 2019 for GWQ1271 – Capricorn Curtis Coast Groundwater Alluvium (dated 6 November 2018) (**Section 6.2**).

- [III] Maximum ET Rate and Extinction Depths.
- [IV] Hydraulic Conductivity Zones (Pilot Points) – Alluvium / Styx Interburden / Coal Seams / Basement Aquifer (Vertical & Horizontal).
- [V] Geological Structure (Fault) Zone of Hydraulic Conductivity [Enhanced or Reduced].
- [VI] Depth Dependence (Depth Function) in Coal Seams.
- [VII] Specific Storage and Specific Yield Parameters.
- [VIII] Spoil Properties in Backfilled Voids.
- [IX] Predictive Sensitivity for Increased Landholder Pumping.

Each of the above matters are discussed and considered separately in **Sections 8.11** and **8.12**.

7.2 MODEL COMPLEXITY, SOFTWARE AND SIMULATION

7.2.1 Model Complexity and Target Model Confidence Level Classification

The numerical groundwater modelling for the CQC Project has been guided by the Australian Groundwater Modelling Guidelines (Barnett *et al*., 2012) which state:

> *"…the capacity to capture real-world complexity in a model is limited."*
>
> *"A balance is needed between simplicity and complexity."*

Levins (1966) also explains that there is always a trade-off in numerical models between generality, precision and realism; it is not possible to maximise all three simultaneously.

That is, there is always a level of uncertainty in model predictions as they can only be built on the data and information available. Simplifying assumptions regarding the direction of flow in aquifers and aquitards are also made to reduce the complexity for the purposes of mathematical analysis of flows (both for steady state and unsteady state systems) (Barnett *et al*. 2012).

The complexity in the groundwater systems has been characterised during the groundwater model conceptualisation (**Section 6.3**) and broader conceptualisations made to simplify the representation of the systems to allow consideration of relevant environmental values and water quality objectives applicable to the hydrogeological units. This is the application of the principle of simplicity.

Relevantly, the model design and construct has considered the updates to the regulatory framework and additional data acquired to characterise the hydrological and landscape setting, geology, soils and geomorphology, and groundwater datasets and dependent assets (including groundwater connectivity and dependence) (**Sections 2.0 to 5.0**, and **Sections 6.1 and 6.2**).

The limited use and general absence of active groundwater users in ML 80187 (**Section 5.2**), the depth to groundwater table (**Section 5.4**), the typically saline nature of the groundwaters (**Section 5.5**) and the targeted groundwater investigations (**Attachments 5 and 7**) all confirm that the groundwater systems are not significant aquifers at the CQC Project. That is, the groundwater systems at the CQC Project are of limited potential.

Considering the above level of complexity, and recognising the previous modelling undertaken by CDM Smith (2018d), the overall target model confidence level classification for the numerical groundwater model being targeted with the improvements is Class 2 and is discussed in **Section 7.9**.

7.2.2 MODFLOW-USG Software

MODFLOW is considered the industry standard, as the most widely used (and accepted) code for groundwater modelling. The CQC Project numerical groundwater model has been developed by HydroAlgorithmics using MODFLOW-USG (UnStructured Grid) which unlike the MODFLOW code uses a control volume finite difference (CVFD) method, rather than a standard finite difference numerical scheme.

The CVFD method allows a model cell to be connected to arbitrary number of adjacent cells, of different shapes as opposed to a standard rectangular grid. Importantly, this allow for grids to better represent and reflect features in reality for the purposes of assessment. Details of the MODFLOW-USG model design and build is provided further below.

7.2.3 AlgoMesh Software

HydroAlgorithmics’ AlgoMesh software has been used to generate the high-quality mesh for the UnStructured Grid for MODFLOW-USG and is described in **Section 7.4.3 (Table 7-4)**.

7.2.4 USG-Transport Software

The numerical groundwater model was run with USG-Transport (Panday, 2019), an advanced version of the MODFLOW-USG code, using its Sparse Matrix Solver (SMS) package for the iterative numerical solution.

The Layer Property Flow (LPF) package was used with the upstream-weighted transmissivity convertible layer type (LAYTYP=4) for all layers, and with CONSTANTCV and NOVFC options applied (full thickness calculation of vertical conductance, without vertical flow correction terms in dewatered conditions). Adaptive Time Stepping (ATS) was used to attain appropriate time step sizes for numerical convergence for the transient model.

The SMS solver settings used in the prediction model are summarised in **Table 7-2**, and further details on the settings are available in Panday *et al*. (2013).

Table 7-2

Sparse Matrix Solver Settings for Improved Numerical Groundwater Model

Sparse Matrix Solver Settings		
Non-linear solution technique	**(NONLINMETH)**	Newton-Raphson iteration with Delta-Bar-Delta (DBD) under-relaxation (1)
Linear solution technique	**(CLIN, LINMETH)**	Stabilised Bi-directional Conjugate Gradient (BiCGStab) in the PCGU solver (BCGS, 2)
Non-linear head closure criterion	**(HCLOSE)**	0.01 m (transient); 0.001 m (steady-state)
Linear head closure criterion	**(HICLOSE)**	0.001 m (transient); 10^{-5} m (steady-state)
Maximum # non-linear iterations	**(MXITER)**	900 (transient); 5000 (steady-state)
Maximum # linear iterations	**(ITER1)**	30 (transient); 100 (steady-state)
DBD learning rate reduction factor	**(THETA)**	0.7
DBD learning rate increment	**(AKAPPA)**	0.07
DBD history factor	**(GAMMA)**	0.1
DBD momentum factor	**(AMOMENTUM)**	0.0
Maximum # backtracking iterations	**(NUMTRACK)**	200
Residual increase tolerance factor	**(BTOL)**	1.1
Backtracking step size factor	**(BREDUC)**	0.2
Residual limit for backtracking	**(RESLIM)**	1.0
Linear preconditioner	**(IPC)**	Incomplete LU factorisation with zero fill (ILU(0)) (2)
Linear solution matrix scaling	**(ISCL)**	None (0)
Linear solution matrix reordering	**(IORD)**	None (0)
Linear solution residual closure criterion	**(RCLOSEPCGU)**	10^{-4} m^3/day

7.2.5 AlgoCompute Platform and HGSUQ Software

HydroAlgorithmics' web-based platform AlgoCompute (HydroAlgorithmics, 2019[xvi]; Merrick, 2017) has been used to perform calibration and sensitivity and uncertainty analysis (i.e. execution of model runs in parallel) (**Attachment 11**).

The model-independent uncertainty quantification software HydroGeoSphere Uncertainty Quantification (HGSUQ) (Miller *et al*., 2018) was also used to generate the Latin Hypercube Sampling (LHS) parameter realisations and orchestrate the model runs within the AlgoCompute environment.

7.3 GEOLOGICAL MODEL

CQCPL provided the 2018 Geological Model to assist with the numerical groundwater flow model build. The 2018 Geological Model included improved correlations for some seams which was not clear in previous models and additional Violet Seam information. From these improved datasets, HydroAlgorithmics extracted floor elevations for the Red, Blue, and Violet Seams in the near vicinity of the CQC Project open cut (**Figure 4-9**).

Beyond the 2018 CQC Geological Model, HydroAlgorithmics has used available drill logs from the groundwater monitoring investigations (**Section 5.1**) (including seam correlations at the historic mine workings at Ogmore and other exploration programs in the region; **Sections 3.4.5 and 3.4.6**) as well as structural, outcrop (including geological cross-sections; **Section 4.2.2**) and surficial geology mapping (**Sections 4.1 to 4.3**). Geological logs and descriptions available on the Government databases (**Section 5.2.2**) were also utilised to confirm or otherwise assign stratigraphic targets.

7.4 MODEL DOMAIN, LAYERS, GEOMETRY AND MESH DESIGN

The numerical groundwater flow model domain and mesh refinement is shown on **Figure 7-1** and is discussed in the following subsections.

7.4.1 Groundwater Model Layering

Model layer geometry has been built consistent with the simplified hydrogeological units conceptual model (**Section 6.3; Figure 6-1**). A zoomed-in and vertically exaggerated cross-section of the model layers for the Styx Coal Measures is presented in **Figure 7-2**. The modelled bottom layers and basement (i.e. Permian and Volcanics) are also shown on **Figure 7-3**.

The geological and stratigraphic framework for the groundwater model layers are summarised in **Table 7-3** and described below.

Upper Layer 1

Layer 1 is included initially as an inactive layer for the potential future inclusion of elevated (rehabilitated) landforms (i.e. out-of-pit waste rock emplacements remaining after backfilling of the voids) for post-mining groundwater modelling scenarios. The layer allows for modelling of localised groundwater table mounding beneath final landforms.

Upper Layers 2-4 (Quaternary & Regolith)

As described in **Section 7.1.2**, the upper layers in the numerical groundwater model have been partitioned and delineated based on consideration of available surficial geology mapping, fluvial geomorphology descriptions and localised TEM survey [**Attachment 5**]), supported by available drill logs, groundwater levels and groundwater quality datasets (**Section 5**).

Table 7-3
Numerical Groundwater Model Layers – Geological and Stratigraphic Framework

	Model Layer		Unit / Geology	Lithology	Indicative Thickness	
Upper	1		Inactive Layer for Elevated Landforms (e.g. Out-of-pit Waste Rock Emplacements)	Predominantly (Bulk) Kx (Broken Overburden / Interburden)	Up to 75 m	
	2		Quaternary / Tertiary / Weathered Regolith (Early Cretaceous / Permian / Volcanics)	Qhe/s, Qhe/m, Qhcm, Qa Qpa, Qr, Qf > Kx Ta Kx Pb, Pbm Pc, Pv, Cp	10 m*	20.2 m
	3			Qa Qpa Ta Kx Pb, Pbm Pc, Pv, Cp	5 m*	
	4		Weathered Regolith (Early Cretaceous / Permian / Volcanics)	Kx Pb, Pbm, Pvw Pc, Pv, Cp	5.2 m*	
Middle	5	Early Cretaceous – Styx Coal Measures	Overburden / Interburden (Upper)	Kx (Overburden)	43.6 m*	242.1 m
	6		Coal Seams (Aggregated to Red Seam)	Kx (Coal)	2.6 m* [3.0 m^]	
	7		Interburden	Kx (Interburden)	55.8 m*	
	8		Coal Seams (Aggregated to Blue Seam)	Kx (Coal)	4.3 m* [4.5 m^]	
	9		Interburden	Kx (Interburden)	21.3 m*	
	10		Coal Seams (Aggregated to Violet Seam)	Kx (Coal)	2.2 m* [2.1 m^]	
	11		Underburden	Kx (Underburden)	112.3 m*	
Bottom	12	Permian	Back Creek Group (including Boomer Formation) and Glenprairie/Wangrabry Beds	Pb, Pbm, Pvw	859 m – 1,005 m*	
	13	Volcanics	Carmila Beds / Lizzie Creek Volcanic Group	Pc, Pv, Cp		
	14		Intrusive Rocks / Connors Volcanic Group	CPvo, CMzg [*West Only*]		
Basement (to -1000 mAHD)						

* Median Model Cell Thickness.

^ Area-Weighted Average Layer Thickness.

Combined with the model grid (unstructured) refinements along watercourses, drainage features and wetlands, these changes allow for improved groundwater connectivity analysis.

Along the reaches of Tooloombah Creek and Deep Creek, in the vicinity of the Project, the Quaternary Alluvium (Qa) has been included in Layer 2, extending laterally consistent with the available surficial geology mapping. Similarly, along the Styx River and Styx River mouth, the mapped Estuarine Deposits (Qhe/s, Qhe/m and Qhcm) have been included in Layer 2. Mapped Pleistocene Alluvium (Qpa) and adjacent Colluvium / Alluvial Fan Deposits (Qr, Qf > Kx) are also included in Layer 2, consistent with the available surficial geology mapping beyond the Qa unit.

However, in the vicinity of Tooloombah Creek where the sandstone bedrock was evident at depth and outcropping (**Section 4.3.1**), whilst the mapped surficial Qa units were not amended (where they may not exist), property zonation has been conservatively applied in the numerical groundwater model beyond the 1:100,000 Scale mapped extent to be generally consistent with TEM survey results in the shallower profile away from the watercourse (i.e. inferred from the TEM survey mapping at 7 mbgl) (**Attachment 5**).

Where the mapped Quaternary units are absent, a 10 m regolith layer is applied in Layer 2 to represent the weathered outcrops of the Early Cretaceous, Permian and Volcanic units, and is reduced where the mapped bottom of weathering is less.

In the far south-east of the model domain, the mapped Tertiary sediments (Ta, Td, TQr) are included in Layer 2 where stratigraphically above the mapped Permian units (Pb, Pbm).

For the purposes of refined groundwater connectivity analysis, and assessment of potential groundwater dependent ecosystems, where the base of weathering surface (i.e. BHWE surface from the geological model [**Section 7.3**]) extended to depths greater than 10 m thickness (Layer 2), the additional profile has been partitioned to incorporate the deeper (lower) mapped Qpa unit / regolith in Layers 3 and 4 (as a 50:50 split) to the base of weathering. Notably, if the distance from the base of Layer 2 (10 mbgl) to the mapped bottom of weathering is < 2 m, Layer 2 takes the entire thickness and Layer 3 is pinched out within the model domain.

As described in **Section 5.1.1**, of the 12 WMP series groundwater monitoring network bores considered screened in the Quaternary alluvium / regolith, all with the exception of WMP05 and WMP29B (which are further downstream respectively), have recorded depth to standing water level of more than 10 m. This partition also allows for the application of increased horizontal conductivity (Kh) values to be applied to the mapped Qa units to better reflect the results of the TEM survey (**Attachment 5**) in the near vicinity of the local watercourses (e.g. WMP04, BH16 and BH01X), and potentially model calibration. The partition also enables more detailed uncertainty analysis to be carried out, whereby changes to modelled hydraulic properties can be investigated in the upper layers as required.

Beneath the combined Quaternary units modelled by CDM Smith (2018), Layers 3 and/or 4 include the weathered subcrops of the Early Cretaceous and Permian units.

Model cells with thickness < 0.2 m have been pinched out throughout the entire model. Therefore, beyond the mapped Quaternary units and Styx Coal Measures (middle layers), the top regolith layer(s) overlie the Lower model layers (Layers 12 to 14).

Middle Layers 5-11 (Early Cretaceous – Styx Coal Measures)

The Early Cretaceous Styx Coal Measures have been separated and the coal seams aggregated to allow the model to apply separate coal and interburden permeabilities based on experience, and supported by laboratory core permeability testwork results conducted on drill core sampled at STX1812 and STX1903 (**Attachment 9**).

The aggregated coal seams have been used to generally align and correlate with the thickest coal plies, and those understood to have been historically targeted and mined at the Styx No.1, No.2 & No.3 State Coal Mines at Bowman and Ogmore, namely (**Section 3.4.5**):

- Red Seam (i.e. ~Top Working Seam at Styx No.3);
- Blue Seam (i.e. ~Bottom Working Seam at Styx No.3); and
- Violet Seam (i.e. ~Lower Seam at Styx No.3).

As described above, beyond the mapped Early Cretaceous Styx Coal Measures where model cells with thickness < 0.2 m have been pinched out, the Permian units (i.e. Back Creek Group and Boomer Formation) are represented in the Lower model layers (Layers 12 to 14).

Bottom Layers 12-14 and Basement (Permian & Volcanic Units)

The bottom (or basement) layers of the model comprise the Permian Back Creek Group (including Boomer Formation), Lizzie Creek Volcanic Group (including Carmila Beds) and underlying Connors Volcanic Group. All layers are cut off at a minimum elevation of -1000 mAHD which means that Layer 12 is the deepest layer in much of the north, central and eastern areas of the model domain, with Layers 13 and 14 pinched out. Where the Back Creek Group subcrops in the west, Layers 13 and 14 then extend to the model basement at -1000 mAHD (**Figure 7-3**).

7.4.2 Geological Structure and Faulting

Geological structure and faulting included within the model mesh has been based on the available geology mapping and cross-sections within the Styx River catchment (**Sections 4.1 and 4.2**). The Explanatory Notes (Malone, 1965) and Withnall *et al*. (2009) have also been used as a guide for strata dip and relative thicknesses of units in the model domain.

Lateral connection groups have been used to create horizontal flow connections across the faults. Sensitivity and uncertainty analyses explore alternative hydraulic properties along the faults; these are discussed in **Sections 8.11.3 and 8.12.1**.

7.4.3 Model Domain

The model domain for the improved numerical groundwater model is generally defined by the Styx River catchment to Charon Point, comprising:

- Tooloombah Creek/Deep Creek sub-catchments;
- Granite Creek/Montrose Creek sub-catchments;
- Wellington Creek catchment (including Stoodleigh Creek sub-catchment); and
- bounded by parts of the Broad Sound and adjoining estuarine systems gazetted as a Declared Fish Habitat Area (FHA-047) (**Section 3.5.1**).

The numerical groundwater model covers an area of approximately 1,600 km^2 extending approximately 57 km north to south and 54 km east to west (**Figure 7-1**). The model mesh cell dimensions (from most refined to coarse) and centred cells are provided in **Table 7-4**.

7.5 MODEL STRESSES AND BOUNDARY CONDITIONS

7.5.1 No Flow and Fixed Head Boundaries

The GHD Pty Ltd independent third-party review comments (20 December 2018) specifically noted that the previous numerical groundwater flow model external boundary conditions were consistent with typical modelling practice and therefore an equivalent approach has been adopted, albeit with changes to reflect the extended model domain and justification for the fixed head (tide) elevation.

The boundary conditions applied in the CQC Project numerical groundwater flow model are displayed in **Figures 7-1, 7-4 and 7-5**.

No flow boundary conditions have been applied in all layers at the topographic ridges of the Styx River catchment (i.e. elevation of the water table is topographically controlled).

Table 7-4
Numerical Groundwater Model Mesh – Cell Dimensions

Desired Approximate Cell Width	Actual Cell Size [sqrt {Cell Area}]	Refined Area / Feature
20 m	13-20 m	CQC Project Open Cut.
30 m	22-28 m	Assessment Stream Reaches (Styx River, Tooloombah 1 & 2, Mamelon 1, Deep 1 & 2).
40 m	35-40 m	Historic Mine Workings.
50 m	30-40 m	Mapped Fault Lines in Vicinity of CQC Project and Surrounds.
120 m	100-110 m	Qa Alluvium Unit.
150 m	100-150 m	Other Streams (outside Qa and Assessment reaches).
200 m	150-180 m	Coastline Area.
500 m	430-450 m (470 m max)	Global Maximum Cell Size.
Cells Centred, No Refinement	Varies	Bore Survey and/or Desktop Bore Search Locations.

A fixed head boundary condition has been applied using the constant head package (CHD) at the Styx River mouth and along the mapped estuarine reach of the Styx River (i.e. to the railway crossing).

As concluded by AGE Consultants (2019) (**Attachment 2; Table A2-3**):

> *The surface processes in the tidal zone of Styx River are dynamic, however on the timeframes that the groundwater model operates it is entirely appropriate to represent this as a constant head.*

The distribution of active cells has been adjusted from the previous modelling to ensure the fixed head is applied above the base of the cell to address AGE Consultants earlier peer review comments (**Table A2-3**), and the design has considered the interactions of nearby drain or evapotranspiration boundary conditions (**Sections 7.5.3 and 7.5.5**) to avoid any short-circuiting inflow to occur.

Based on a review of tidal influence and long-term sea level records (**Section 3.3**), the chosen elevation of the fixed head boundary applied was 3.5 mAHD. A sensitivity range of 2 mAHD (as previously modelled) to 4.5 mAHD has been considered in the uncertainty analysis (**Section 8.11.3**).

When selecting the fixed head boundary condition, and sensitivity ranges, specific consideration was made of possible corrections of coastal heads as noted in the methods published by Lu *et al*. (2015). However, no changes were made on the basis that the differences (depending on the confining nature and applied aquifer thicknesses) were generally less than 5 cm for an unconfined aquifer, and less than 0.5 m for a 30 m thick, confined aquifer with a density factor (alpha) of 33.3.

Tide monitoring would continue to be recorded periodically to allow the range of predicted stage water levels in the Styx River to be validated and range of constant head boundary conditions considered (**Section 10.1.3**).

7.5.2 Inactive and Pinched-Out Areas

Areas beyond the model domain extent shown on **Figure 7-2** are inactive.

Select layers are pinched out within the model domain where non-existent, for example, the Styx Coal Measures (Layers 4-11) do not exist in the far west of the model domain, nor beyond the fault / interface with the Back Creek Group in the east.

7.5.3 Watercourses and Drainage Features

All river cells applied within the model domain are shown on **Figure 7-4**. The key watercourses and drainage features listed in **Table 7-5** have been applied in the numerical groundwater flow model generally consistent with those described in **Sections 3.2.1 to 3.2.5**.

All the key river (and drainage) reaches located within the model domain have been assigned as river cells and partitioned consistent with the conceptual groundwater model (for separate assessment purposes to align with the *Water Act 2000*).

As an improvement to the numerical groundwater model, river cells (with Stage Depth > 0 m) are used instead of drain cells in select reaches which, as correctly identified by the peer review (**Table A2-5**), could previously only simulate gaining conditions. Use of river cells has the benefit of simulating losing conditions, particularly if such conditions were to be enhanced during and/or post-mining. The different functions of drain and river cells are shown conceptually on **Figure 7-5**. It is important to note the seasonal conditions and how this is relevant as discussed in **Section 6.3.3**, particularly when recognising the five yearly, annual and monthly stress period lengths used for the numerical groundwater model (**Section 7.6**).

River cell widths in the model domain were assigned ranging from 5 m in the upper reaches of watercourses to 30 m at the Styx River mouth and is relevantly discussed for the river bed conductance values below.

It is recognised that use of the MODFLOW Stream cell type with calibration to observed gains or losses in local watercourses can also be used in numerical groundwater models. However, as evidenced by the available datasets presented in **Section 3.3**:

- long term mean sea levels records (3.42 m and 2.47 m) are available for a 20-30 year period (and is greater than the 18 year CQC Project operations period);
- groundwater level measurements have been recorded at the alluvial groundwater bore WMP29A and compared with predicted daily average tides at Hay Point, Rosslyn Bay, Stanage and McEwin Islet (**Graph 3-4**);
- refined hourly datalogging at WMP29A has also occurred which, as shown in **Graph 3-5**, the amplitude has generally been less than 5 cm to 10 cm (despite greater amplitudes at coastal tide monitoring locations); and
- maximum surface water (tidal) fluctuations observed and recorded in the Styx River at the Ogmore Road bridge crossing (**Table 3-5**) are experienced for only a short timeframe associated with high tides.

Importantly, the improved numerical groundwater model stress periods are for at least monthly (not hourly or daily) intervals. Furthermore, given the downstream distance to the boundary of the Broad Sound Fish Habitat Area (FHA-087) (more than 8 km along the centreline of the watercourses near the CQC Project), and demonstrated local hydraulic properties (lower permeabilities) of the Quaternary Pleistocene Alluvium, the inclusion of short duration runoff events (beyond recharge already applied based on site-specific rainfall datasets for the model calibration period described in **Section 7.5.4**) would unnecessarily over-parameterise the model.

Table 7-5
Key River (and Drainage) Reaches Assigned within the Model Domain

Feature / Reach	Location	Cell Type	MODFLOW RIV Package Attributes
Broad Sound Declared Fish Habitat Area [FHA-047] / Tidal Reach 1	Styx River Mouth	River [~35 km Boundary]	[Constant/Fixed Head 3.5 mAHD]
Styx River / Tidal Reach 2	Downstream of the Granite/Montrose Creek confluence	River [0.8 km]	Stage Height = DEM Stage Depth = 2 m RIVWidth = 30 m
Styx River / Tidal Reach 3	Upstream of the Granite/Montrose Creek confluence	River [5.3 km]	Stage Height = LiDAR Stage Depth = 1 m RIVWidth = 20 m
Tooloombah Creek / Defined Watercourse Reach 1^	Downstream of the Deep Creek confluence	River [1.7 km]	Stage Height = LiDAR Stage Depth = 1 m RIVWidth = 20 m
Tooloombah Creek / Defined Watercourse Reach 2	Upstream of the Deep Creek confluence to Mamelon Creek confluence	River [9.3 km]	Stage Height = LiDAR Stage Depth = 1 m RIVWidth = 10 m
Tooloombah Creek / Defined Watercourse Reach 3	Upstream of the Mamelon Creek confluence to Clive Gully confluence	River* [19.9 km]	Stage Height = LiDAR Stage Depth = 0 m RIVWidth = 10 m
Deep Creek / Defined Watercourse Reach 1	Downstream of Brussels Creek confluence	River* [17.5 km]	Stage Height = LiDAR Stage Depth = 0 m RIVWidth = 10 m
Deep Creek / Reach 2	Upstream of the Brussels Creek confluence	River* [20.8 km]	Stage Height = LiDAR Stage Depth = 0 m RIVWidth = 5 m
Mamelon Creek / Defined Watercourse 1	To Kyour Creek confluence	River* [4.8 km]	Stage Height = LiDAR Stage Depth = 0 m RIVWidth = 10 m
Wellington Creek / Defined Watercourse 1	Downstream of Wangraby Creek confluence	River	Stage Height = LiDAR Stage Depth = 2 m RIVWidth = 20 m
Wellington Creek / Defined Watercourse 2	Upstream of Wangraby Creek confluence to Landsborough Creek confluence	River	Stage Height = LiDAR Stage Depth = 1 m RIVWidth = 10 m
Wellington Creek / Defined Watercourse 3	Upstream of Landsborough Creek confluence	River*	Stage Height = LiDAR Stage Depth = 0 m RIVWidth = 10 m
Wangraby Creek / Defined Watercourse 1	To Wellington Creek confluence	River*	Stage Height = LiDAR Stage Depth = 0 m RIVWidth = 5 m
Landsborough Creek (and North Branch) / Defined Watercourse 1	To Wellington Creek confluence	River*	Stage Height = DEM Stage Depth = 0 m RIVWidth = 10 m
Ewan Creek / Defined Watercourse 1	To Wellington Creek confluence	River*	Stage Height = DEM Stage Depth = 0 m RIVWidth = 5 m

^ Within identified tidal transitional zone.

* River cells have been used (as opposed to Drain cells) with Stage = 0 m.

It is noted that additional head observations are available on Tooloombah Creek at the pool (and invert) upstream (and downstream) of the Gauging Station, and upstream (TC) based on survey level measurements, however were not verified and available at the time of modelling, but was subsequently validated (**Section 7.8.1**). It is understood more refined site-specific analysis is also being considered separately by Orange Environmental Pty Ltd and Eco Logical Australia Pty Ltd (2020d).

As described in **Section 7.5.1**, tide monitoring would nevertheless continue to be recorded periodically to validate the range of predicted stage water levels in the Styx River undertaken as a component of the uncertainty analysis (i.e. range of constant head boundary conditions considered) (**Section 10.1.3**).

River Bed Conductance

Conductance values have been applied to river cells based on averaged bed areas (length x approximate widths ranging from 5 m [default], 10 m, 20 m to 30 m [at the Styx River mouth]) for each of the key river (and drainage) reaches in **Table 7-5**.

Recognising that the bed of watercourses typically comprises silty/clayey material at its base, a river bed hydraulic conductivity value (K) of 0.01 m/day has been used.

7.5.4 Rainfall and Flood Recharge

Transient recharge is applied based on a constant proportion of rainfall for the averaging period. This is evident and discussed in **Sections 7.7.4 and 7.7.6**.

Consistent with the findings presented in Section 10.5.6.6 of CDM Smith (2018), it can be expected that higher rates of recharge occur generally along watercourses during flow events due to leakage (from the watercourse or drainage line) and that recharge of the associated alluvial soils will be higher than elsewhere where basement rocks (less permeable) outcrop. Consistent with the conceptualisation (**Section 6.3**), where the less consolidated Cenozoic Sediments (i.e. Quaternary Alluvium) are present, higher recharge rates have been applied relative to the mapped Quaternary Pleistocene Alluvium (**Table 7-6**).

Table 7-6
Adopted Rainfall Recharge within the Model Domain

Recharge Type	Lithology / Timing				Annual Average Recharge [mm/year]	% of Annual Rainfall
1. Diffuse Moderate	Qhe/s, Qhe/m, Qhcm,		Qa		10	1.3%$^{+}$
	[Annual]					
2. Diffuse Low	Qpa, Qr, Qf > Kx				4.5	0.6%^
	[Annual]					
3. Diffuse Very Low	Ta	Kx	Pb, Pbm	Pc, Pv, Cp	3	0.4%
	[Annual]					

^ Value derived by chloride mass balance method (CDM Smith, 2018).
$^{+}$ Higher value applied to better reflect conceptualisation and modelling experience to address earlier peer review commentary.

Long-term and site-specific rainfall datasets within the Styx River catchment appear to correlate well (**Graph 3-3**). It is recognised that whilst higher average rainfall records are available at the St. Lawrence Post Office, it is north and beyond the Styx River catchment, and would only have the effect of higher recharge to north-western and elevated catchments (e.g. Granite Creek) in the model domain.

The three (3) episodic flood recharge events which have occurred since 2010 (i.e. 2010-11; 2013 and 2017) (**Graph 3-2**) are recognised in the annual and monthly rainfall totals in the transient calibration period as discussed in **Section 7.7.2**. However, for forward predictions, such episodic flood (recharge) events would not be specifically applied in the model and therefore allows for conservative assessment.

River Bed Conductance

As described in **Section 7.5.3**, a river bed hydraulic conductivity (K) value of 0.01 m/day has been used and applied to river cells.

It is noted that river bed conductance values can be factored (if necessary) during calibration (to better reflect flood recharge) and subsequent uncertainty analysis (for lower and higher K sensitivity scenarios) and is discussed separately in **Sections 7.7.6, 8.11.1** and **8.12.2**.

7.5.5 Evapotranspiration

Two evapotranspiration maximum rates have been applied across the model domain at the surface:

- 1,239 mm/year in mapped (Qhe) Quaternary Estuarine Alluvium, based on BOM pan evaporation multiplied by a conversion coefficient of 0.7 for lake evaporation; and
- 715 mm/year in all other areas based on average areal actual evapotranspiration (annual) at the CQC Project (**Figure 3-3**).

The evapotranspiration rates are reduced linearly with depth to ET extinction depths dependent on the lithology (i.e. mapped unconsolidated sediments), mapped high, moderate and low potential GDE areas, and vegetation cover as stated in **Table 7-7** and are shown schematically on **Figure 7-6**. The delineation of zones within the model domain (and extinction depths) where ET rates have been applied are shown on **Figure 7-7**.

The evapotranspiration rates applied are therefore set near the Actual ET, and the extinction depths generally consistent with Canadell *et al*. (1996) based on maximum rooting depths of vegetation types and Shah *et al*. (2007). The same extinction depths were applied to the unconsolidated Quaternary (Qa, Qpa) sedimentary regardless of vegetation type, recognising that across CQC Project area and surrounds the groundwater table was generally at depths greater than 10 mbgl (away from the watercourses). As discussed in **Section 5.5.8**, the extinction depths applied to depths less than 8 mbgl is also consistent with the findings elsewhere in Qld as demonstrated in Jones *et al*. (2019).

Table 7-7
Adopted Evapotranspiration Rates and Extinction Depths within the Model Domain

Maximum Evapotranspiration Rate at Surface/Ground Level	Lithology / Feature within Model Domain	Extinction Depth
1,239 mm/year [3.4 mm/day]	Qhe/s, Qhe/m, Qhcm	Linearly to 3 mbgl
715 mm/year [2.0 mm/day]	Qpa, Qr, Qf > Kx Qa	Linearly to 8 mbgl
	High, Moderate and Low Potential GDEs^ [Beyond Mapped Quaternary Units]	
	All Other Areas including Cleared, Cropped and Grassed.	Linearly to 3 mbgl

^ BOM GDE Atlas Mapping.

Further, the shallow bore holes (BH1 to BH3) installed in Wetland 1 (**Section 5.1.4**) appear to also support the application of extinction depths from the surface to approximately 8 mbgl with unsaturated profiles recorded and increasing moisture profiles from approximately 8 mbgl. WRM Water & Environment Pty Ltd (2020) also identifies varying densities of vegetation across the tenements.

It is noted that during the conceptualisation (**Section 6.3.7**), approximately 74% of the previous groundwater model outputs in the water balance related to ET.

7.5.6 Historic Mining and Investigations

As described in **Section 3.4.5**, there has been a long history of coal mining in the Styx River Coalfield. Based on a review of past geological survey reports and explanatory notes, the following indicative historic mining sequence has been derived and is presented in **Table 7-8**.

The model stress periods (**Section 7.6**) for the transient pre-calibration have been assigned as closely as possible to be generally consistent with the historic mining sequence as presented in **Table 7-8**.

Drain cells have been assigned to the bottom of the relevant coal seam layer (generally consistent with the depths presented in **Tables 3-6 and 3-7**) during the mining periods, with application of TVM properties to account for (partial) void space (noting it has been assumed the historic workings are not fully goafed/ subsided i.e. pillars remain).

Therefore, the following hydraulic properties have been used for the post-mining recovery periods:

- $K_{Horizontal} = K_{Vertical} = 100$ m/day;
- $S_y = 0.5$ (assuming ~50% material removed within the model layer); and
- S_s = host properties (generally equivalent to water 4.7 x10^{-6} m^{-1}).

Table 7-8
Indicative Historic Mining Sequence –
Styx No.1, No.2 & No.3 State Coal Mines and Bowman Coal Mine

Year	Historic Mining Area								
	Styx No.1 & No.2 State Coal Mine		Styx No.3 State Coal Mine		Bowman Coal Mine Level				
	Styx No.1	Styx No. 2	Top Working Seam	Bottom Working Seam	No.1	No.2	No.3	No.4	No.5
1918-19	✓	✓							
1920-24	*	✓	✓						
1925-29		*	*	✓					
1930-39				✓	✓	✓	✓	✓	✓
1940-48^				✓	*	*	✓	✓	✓
1949-51				✓			*	*	*
1952-64			✓	*					
1964+			*						

* Mining ceased. Recovery Commenced.
^ Upper workings were sealed after 1939.

7.6 SIMULATION PERIOD AND TEMPORAL DISCRETISATION

The transient simulation period for the groundwater model has been extended specifically to:

- increase the calibration datasets; and
- allow for cumulative assessment of historic mine workings.

A number of model variants are being used and temporal discretisation varied accordingly to reflect available baseline datasets (i.e. 2010-11, 2012 and 2014), refined baseline datasets (2017-2019) and details of other stressors (i.e. historic mine workings, future mine design and long-term use).

Additional model variants are used to allow separate reporting and quantification of Project alone from cumulative effects utilising null model runs for comparison (**Table 7-9**).

Table 7-9
Model Variants

Model Variant		Reason	Comments
1	Steady State Calibration Model	Establish Pre-Mining Groundwater Levels (Existing Conditions)	Recognises that groundwater levels WMP11, WMP11D, WMP13, WMP29C and WMP29D may potentially be historically mine-affected and therefore calibration targets adjusted accordingly.
2	Pre-Calibration Model	For Cumulative Assessment (Prior to CQC Project)	Includes historic mine workings with application of drain cells for historic mining periods and then allows continued recovery of historic workings. Steady State Pre-Mining Groundwater Levels + a) Historic Mining (1918-1948) [Bowman] + b) Historic Mining (1924-1964) [Ogmore] + c) Historic Recovery to Transient Calibration Commencement (December 2010)
	Transient Calibration Model	Includes PEST Calibration (Prior to CQC Project)	Follows Pre-Calibration Model and allows for continued recovery of historic mine workings. Pre-Calibration Model + Transient Calibration Period (Jan 2011-Sep 2019) + Historic Recovery to Transient Calibration End (End September 2019)
	Transient Prediction Model	During Mining For Cumulative Assessment (CQC Project + Historic Workings)	Follows Transient Calibration Model and allows for continued recovery of historic workings. Transient Calibration Model + Historic Recovery to Project Mining Period Commence (June 2020) + Project Mining Period (Jul 2020-Jul 2038) + Historic Recovery to End of Project Mining Period (July 2038)
	Transient Recovery Model	Post Mining For Cumulative Assessment (CQC Project + Historic Workings)	Follows Transient Prediction Model and allows for continued recovery of both historic workings and CQC Project. Transient Prediction Model + Historic Recovery for Project Mining Period + Mine Closure and Post Mine Recovery (to December 2538)
3	Null Model 1	During Mining (Null)	Null Model to allow for Project Alone drawdown impact reporting: (4) – (6) = Project Alone Transient Calibration Model + Historic Recovery to Project Mining Period Commencement (June 2020) + Historic Recovery to End of Project Mining Period (July 2038)
	Null Model 2	Post Mining (Null)	Null Model to allow for Project Alone recovery reporting: (5) – (7) = Project Alone Null Model 1 + Historic Recovery to End of Recovery Period (December 2538)

The following stress periods (and timeframes) have been adopted for the extended calibration datasets:

- Steady State [To represent pre-mining in Styx Coalfield / Existing Conditions[29]];
- Transient Pre-Calibration (**Stress Periods 1-18 – 5 Year Increments**) [1919 to 1964, then to 2009] (application of drains in old workings to 1964 generally consistent with **Table 7-8** and then recovery);
- Transient Calibration A (**Stress Periods 19-26 – Annual Increments**) [2010-2016] (include baseline groundwater datasets collected during previous exploration and data collection campaigns);
- Transient Calibration B (**Stress Periods 27-59 – Monthly Increments**) [January 2017 to September 2019] (include refined baseline groundwater datasets);
- Transient Prediction – Prelude (**Stress Periods 60-68 – Monthly Increments**) [October 2019 to June 2020];
- Transient Prediction – Mining (**Stress Periods 69-284 – Monthly Increments**) [July 2020 – June 2038];
- Transient Recovery – Mine Closure [Backfill] (**Stress Periods 285-296 – Monthly Increments**) [July 2038-June 2039];
- Transient Recovery – Mine Closure (**Stress Periods 297-300 – Annual Increments**) [July 2039-December 2042];
- Transient Recovery – Post-Mining (**Stress Periods 301-319 – 5 Year Increments**) [January 2043-December 2138]; and
- Transient Recovery – Long-term (**Stress Period 320 – 400 Year Increment**) [January 2139-December 2538].

7.6.1 Stress Period Lengths

As presented in **Table 7-10**, the stress period lengths range from monthly (for refined calibration, mine prediction and mine closure) to annual (for extended calibration and post-mining), five yearly (for pre-calibration and 100 years post mining) and 400 years (for long-term post-mining recovery).

7.6.2 Time Steps

As described in **Section 7.2.4**, Adaptive Time Stepping (ATS) was used to attain appropriate time step sizes for numerical convergence for the transient model. For example, the initial time step length for longer stress periods 1-26 was 30 days with a length factor increase and decrease of 1.5 and 2.0 respectively, and minimum and maximum of 0.01 and 183 days.

For shorter stress periods 60-296 the initial time step period was 1 day with the same length factor increases and decreases, and minimum and maximum of 0.05 and 7 days.

7.7 MODEL CALIBRATION

7.7.1 Calibration Approach

Calibration of the numerical groundwater model has focussed on history-matching groundwater level observations with model predicted levels. More than 1,000 individual groundwater level measurements have been analysed at 138 locations within the model domain (**Sections 5.1 to 5.4 and Attachments 4 and 8**).

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[29] Calibration datasets exclude groundwater monitoring network bores considered to have been potentially affected by the influence of historic mine workings (i.e. WMP29A-E, WMP11, WMP11D, WMP13 and WMP10D).

Table 7-10
Model Stress Periods Overview

Period		Increment	Stress Periods									
			0	1-18	19-26	27-59	60-68	69-284	285-296	297-300	301-319	320
	Steady State	-	✓									
Transient	Pre-Calibration – Historic Mining [1919-1964]	5 Years		✓								
	Pre-Calibration – Historic Recovery [1964-2009]	5 Years		✓								
	Calibration A [2010-2016]	Annual*			✓							
	Calibration B [2017-2019]	Monthly				✓						
	Prediction – Prelude [2019-2020]	Monthly					✓					
	Prediction – Mining^ [2020-2038]	Monthly						✓				
	Recovery – Mine Closure [Backfill] [2038-2039]	Monthly							✓			
	Recovery – Mine Closure [2039-2042]	Annual*								✓		
	Recovery – Post-Mining [2043-2138]	5 Years									✓	
	Recovery – Long-Term [2139-2538]	400 Years										✓

^To end of ROM coal mining, prior to final backfilling.
*One six month increment to transition and align with post-mining periods.

Despite the installation of stream flow gauges, there were no flow events recorded at the time of cut-off for model calibration datasets which was a known/planned limitation, recognising that the numerical groundwater model would be subject to robust uncertainty analysis (**Sections 8.11 and 8.12**) and future review and validation (**Section 10.9**). Thus, no reliable stream flow, baseflow or seep/spring flow data was available to calibrate at the time. Similarly, as the CQC Project is yet to commence, model calibration to mine inflow or dewatering datasets is unable to be carried out.

As discussed in **Section 7.7.4** (and **Table 7-9**), it is recognised that several groundwater monitoring sites WMP11, WMP11D, WMP13, WMP29C and WMP29D cannot be confidently relied on as being “unimpacted” by historic mining at Bowman and/or Ogmore and therefore have been investigated separately.

Whilst data north-east of the CQC Project in the Back Creek Group (and east of the fault) was also unavailable at the time of cut-off for model calibration datasets (i.e. WMP31), it is recognised that vibrating wire piezometers would in any case require several months for deep pressures to equilibrate post-construction, and was also a planned exclusion, nevertheless would be available for future validation (**Section 10.9**). Available datasets are presented in **Attachment 8** (**Graph A8-54**).

Both manual (initially) and automated calibration methods have been used, with manual calibration only used initially to assess model stability, before then being automated using the PEST[xvii] suite of software (Doherty, 2015). PEST parameters used were K_H, K_V, S_s, S_y and K_H/%Infiltration (i.e. recharge) at zoned pilot points.

Steady State

Steady state calibration targets within the model domain have been determined comprising average groundwater level measurements (or lack thereof, where dry) at:

- 38 exploration drill holes (STX series);
- 6 shallow drill holes (BH1-BH6);
- 47 groundwater monitoring network bores (WMP Series)[30];
- 30 landholder bores recorded during the previous bore surveys (i.e. 2017); and
- 69 other registered bores on the Government databases.

A breakdown of each steady state calibration target assigned to each numerical groundwater model layer is provided in **Table 7-11**.

Table 7-11
Steady State Targets Per Model Layer

Lithology / Layer			Steady State Targets$^{\#}$
2	Qhe/s, Qhe/m, Qhcm	Qa / Regolith	WMP05, WMP21 | BH1, BH2, BH4, BH6 | BH03X, BH06X, BH16, BH20, BH24, BH25, BH26, BH29, BH37, Well01 | 111566
3	Qa / Regolith		WMP28, WMP29A | BH01X, BH04, BH05X
	Qpa / Regolith		WMP02, WMP04, WMP08, WMP09, WMP17, WMP18
4	Kx [o] / Regolith		WMP10, WMP11, WMP12, WMP15, WMP24, WMP26, WMP29B | 187278
5	Kx [o]		WMP04D, WMP11D, WMP13, WMP17D, WMP18D, WMP21D | BH5 | STX00105, STX00109, STX00136C
6-10	Kx [i]		WMP22A, WMP22B, WMP23A, WMP25, WMP29C, WMP29D, WMP30A, WMP30B | BH3 | STX00077, STX00090, STX00093, STX00095, STX00096C, STX00097, STX00103, STX00104, STX00113, STX00114, STX00135C, STX00137, STX00170, STX00204, STX1203C
11	Kx [u]		WMP06, WMP07, WMP08D, WMP10D, WMP14, WMP16^{+}, WMP27, WMP29E | STX00038, STX0073C, STX00081, STX00091, STX00100, STX00112, STX00127, STX00130, STX00205, STX0126B, STX0145C, STX1200, STX1201C, STX1202C, STX1204L, STX1205, STX1205L, STX1807_2 | 91746, 91748, 91749, 91750, 91751, 91752, 91753
12-13	Pb, Pbm	Pc, Pv Cp	WMP16D, WMP19^, WMP19D, WMP20^, WMP20D, WMP22C, WMP23B, WMP30C | STX1204, STX1806_2 | BH01, BH02X, BH04X, BH06, BH07, BH08, BH13, BH17, BH19/88890, BH21, BH22, BH23, BH28, BH30, BH32, BH35 | 67650, 67651, 88889*, BH18/88891*, 88892, 91455, 91456, 91457, 91844, 97381, 97641, 97654, 97827, 97828, 97830, 111311, 111312, 111428, 111429, 111480, 111543, 111559, 111560, 111565, 111568, 111593, 122160, 122161, 122164, 122987, 122989, 136063, 136065, 136067, 136562, 151113, 151938, 151942, 151948, 151949, 161189, 161224, 161292, 161293, 161351, 161355, 187293, 187294, 187295, 12700003
14			97826, 122994, 161437, 161438, 161478, 161612, 161945, 161946

*Tertiary unit.
[#] 97825 not included as topography ranges from 250 to 350 mAHD within a single cell.
[+] WMP16 has been assigned to Styx Coal Measures (Underburden) Layer 11 based on model geometry / shallow depth.
^ WMP19 and WMP20 have been assigned to Regolith Layer 2 based on model geometry / shallow depth.

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[30] Includes WMP10D, albeit turned into an exploration drill hole.

Pre-Calibration and Transient Calibration

Calibration was focused on available groundwater levels recorded between 2010 and 2019, with refined 'history-matching' during monthly periods between 2017 and 2019 (**Attachment 8**).

Where drilling records or landholder bore information existed, the steady state groundwater levels were used in the pre-calibration period (prior to 2010). That is, the steady state calibration targets within the model domain were again utilised for the transient calibration, but the groundwater levels recorded at the WMP Series bores the focus, along with several other landholder bores with temporal records.

As noted above, despite the installation of gauging stations on Tooloombah Creek and Deep Creek and more recent flow datasets, there was no flow data against which to calibrate the model during the calibration period. It is however noted that the extended below average rainfall conditions (and therefore dry reaches of the watercourses) has however allowed for useful comparisons and correlation with trends and is evident in the modelled groundwater level hydrographs (**Section 7.7.4** and **Attachment 8**).

A description and summary of the improved model performance for the numerical groundwater model in relation to observed water levels are presented in **Section 7.7.4**.

7.7.2 Modelled Groundwater Recharge

As described in **Section 7.5.4**, variable rainfall recharge has been applied across the model domain consistent with the conceptualisation.

The moderate initial recharge value (1.3%) of annual rainfall applied to the Quaternary Alluvium (Qa and Qhe) units addresses the peer review comment that adopted alluvium recharge in the previous CDM Smith (2018) numerical groundwater model was considered low at 0.6%.

This was subsequently increased to 1.51% for the Quaternary Alluvium in the calibrated steady state model when used as starting values for the transient calibration.

7.7.3 Modelled Hydraulic Properties

As discussed in **Section 6.3**, the initial hydraulic properties targeted were assigned for each layer based on the updated conceptual groundwater model (**Table 6-4**). The initial anisotropy factor (x 10) and specific yield were assigned consistent with the core permeability (**Graph 5-9**) and porosity testwork (1.0%).

Appropriate ranges were then identified for different zones within each model layer based on the aquifer testing, literature review and prior modelling hydraulic properties compilation in **Section 5.6** and used as model allowable ranges (**Table 7-12**). Appropriate ratios (i.e. K_H / K_V) and magnitudes (i.e. specific yield >1%) were also considered.

The ranges (and where relevant log mean values) of adopted hydraulic properties at the end of the transient calibration are also listed in **Table 7-12**. Storage properties applied within the model layers are also presented in **Table 7-13**.

Spatial variability has been incorporated in other layers in the updated numerical groundwater model via the use of pilot points. Pilot point properties spatial plots for each layer are provided in **Attachment 12**.

Table 7-12
Transient Calibration Hydraulic Properties Ranges and Average Values

Layer	Zone Number	Range (or Log Mean) of Applied $K_{HORIZONTAL}$ [m/day]	Model Permitted Ranges ($K_{HORIZONTAL}$ [m/day])	Anisotropy Log Mean $K_{HORIZONTAL}$/ $K_{VERTICAL}$ [Ratio]	Model Permitted Ranges $K_{HORIZONTAL}$/ $K_{VERTICAL}$ [Ratio]
2	21 (Regolith)	**4.0**	0.25-4	5.3	1-250
	22 (Qa)	**20**	5-20	26.7	1-250
	23 (Qpa)	**4.1**	2.05-8.2	2.5	1-250
	24 (Tertiary)	0.26-(**0.54**)-2.18	0.25-4	15.9	1-250
3	31 (Regolith)	**4.0**	0.25-4	11.5	1-250
	32 (Qa)	1.96-(**4.61**)-19.69	5-20	224.5	1-250
	33 (Qpa)	0.25-(**2.28**)-4.24	2.05-8.2	17.8	1-250
	34 (Tertiary)	0.25-(**0.25**)-0.26	0.25-4	11.2	1-250
4	4 (Regolith)	0.1-(**0.98**)-3.99	0.1-4	123.8	1-250
5	5 (Styx Overburden)	**0.2**	0.002-0.2	98.0	1-250
6	6 (Red Seam & Above)	0.03-(**0.15**)-1.37	0.0002-2.2	5.9	1-250
7	7 (Styx Interburden)	**0.03**	0.0003-0.03	22.5	1-250
8	8 (Blue Seam & Above)	0.0012-(**0.02**)-0.15	0.0002-2.2	5.1	1-250
9	9 (Styx Interburden)	0.000295-(**0.00162**)-0.01	0.0003-0.03	17.0	1-250
10	10 (Violet Seam & Above)	0.000389-(**0.06**)-2.09	0.0002-2.2	7.2	1-250
11	11 (Styx Underburden)	0.000402-(**0.00393**)-0.04	0.0004-0.04	7.3	1-250
12	121 (Back Creek Group)	**0.0004**	0.0004-0.04	1.0	1-250
	122 (Glenprairie / Wongrabry Beds)	**0.004**	0.00004-0.004	1.0	1-250
13	13 (Lizzie Creek Volcanics)	0.0000388-(**0.000123**)-0.00375	0.00004-0.004	1.0	1-250
14	14 (Intrusives / Connors Volcanics)	**0.000001**	0.000001-0.0001	1.0	1-250

Table 7-13
Transient Calibration Storage Properties Ranges and Average Values

Layer	Zone Number	Log Mean of Applied Specific Storativity (S_s) [1/m]	Model Permitted Ranges (Storativity (S_s) [1/m])	Log Mean of Applied Specific Yield (S_y) [%]	Model Permitted Ranges (Specific Yield (S_y) [%])
2	21 (Regolith)	0.000013	0.0000013-0.000013	0.47	0.05-1
	22 (Qa)	0.000013	0.0000013-0.000013	1.90	0.2-4
	23 (Qpa)	0.000013	0.0000013-0.000013	1.00	0.1-2
	24 (Tertiary)	0.000013	0.0000013-0.000013	1.04	0.1-2
3	31 (Regolith)	0.000013	0.0000013-0.000013	0.49	0.05-1
	32 (Qa)	0.000013	0.0000013-0.000013	2.07	0.2-4
	33 (Qpa)	0.000013	0.0000013-0.000013	0.79	0.1-2
	34 (Tertiary)	0.000013	0.0000013-0.000013	1.12	0.1-2
4	4 (Regolith)	0.000013	0.0000013-0.000013	0.57	0.05-1
5	5 (Styx Overburden)	0.00000514	0.0000005-0.000013	0.53	0.05-1
6	6 (Red Seam & Above)	0.00000485	0.0000005-0.000013	0.57	0.05-1
7	7 (Styx Interburden)	0.00000485	0.0000005-0.000013	0.50	0.05-1
8	8 (Blue Seam & Above)	0.00000505	0.0000005-0.000013	0.52	0.05-1
9	9 (Styx Interburden)	0.00000505	0.0000005-0.000013	0.58	0.05-1
10	10 (Violet Seam & Above)	0.00000497	0.0000005-0.000013	0.52	0.05-1
11	11 (Styx Underburden)	0.00000459	0.0000005-0.000013	0.51	0.05-1
12	121 (Back Creek Group)	0.00000458	0.0000005-0.000013	0.52	0.05-1
	122 (Glenprairie / Wongrabry Beds)	0.00000324	0.0000005-0.000013	0.33	0.05-1
13	13 (Lizzie Creek Volcanics)	0.00000534	0.0000005-0.000013	0.53	0.05-1
14	14 (Intrusives / Connors Volcanics)	0.00000506	0.0000005-0.000013	0.45	0.05-1

7.7.4 Modelled Groundwater Level (Observed / Computed) Comparisons

Steady State Calibration Results

The groundwater level steady state calibration (observed versus computed groundwater levels) are presented in **Graph 7-1** and the corresponding performance statistics tabulated in **Table 7-14**.

Table 7-14
Model Calibration Statistics

Statistic	Steady State Calibration^	Transient Calibration
Sum of Squares Error	5,487.8 m^2	6,782.0 m^2
Mean Square Error	39.8 m^2	13.1 m^2
Root Mean Square Error	6.3 m	3.6 m
Scaled Root Mean Square (SRMS) Error	**3.49%**	**2.01%**
Observed Minimum	-21.5 m	-21.5 m
Observed Maximum	159.1 m	159.1 m
Observed Range	180.6 m^	180.6 m^

^ The two observed head values at 300 mAHD (**Graph 7-1**) were removed to avoid statistical bias as previously identified by peer review.

Notably, the two observed head values in the far south-west of the groundwater model domain at approximately 300 mAHD were removed from the statistical summaries to avoid bias (i.e. lowering of the %SRMS error). Bore 122994 (at 305 mAHD) is located at the head of the Tooloombah Creek South Branch in the Broadsound Range. Bore 97825 appears to be located in very steep topography and given the resolution of the model mesh cell (which varies from 350+ mAHD to 250 mAHD) explains the differential between the observed and simulated heads.

Transient Calibration Results

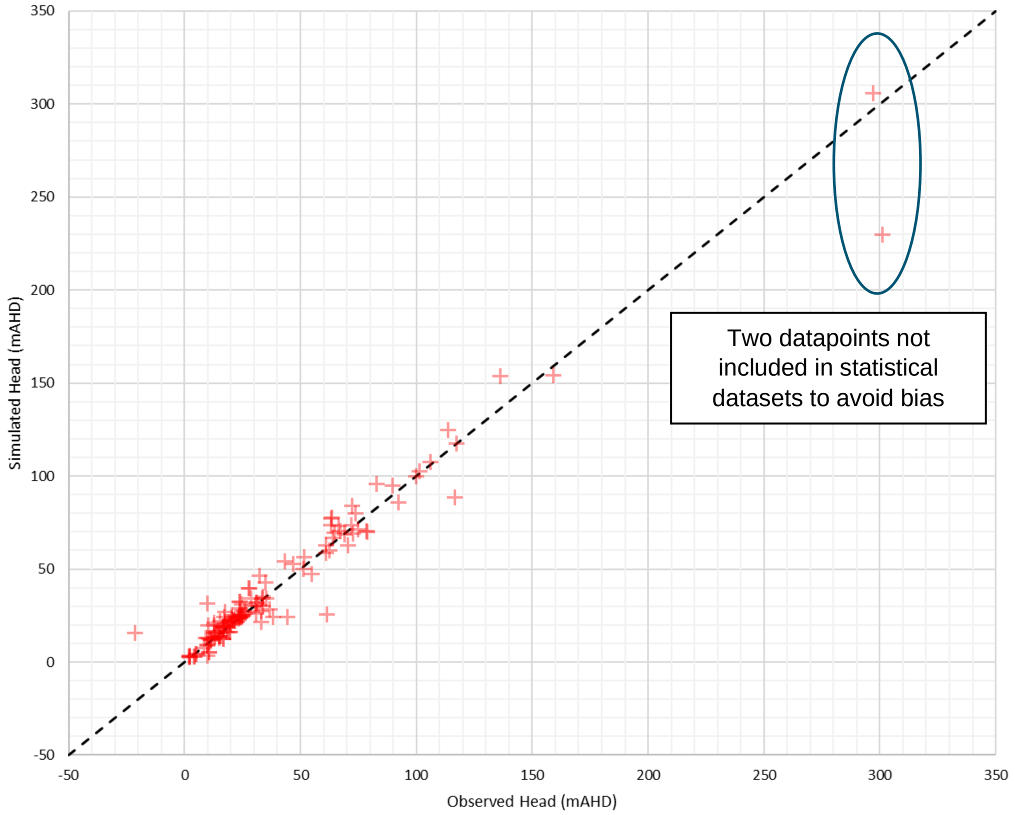
The results of the pre-calibration model run are shown on **Figures 7-8[a] to 7-8[d].**

The transient groundwater level calibration (temporal observations versus computed groundwater levels over time) are presented in **Graph 7-2** and the corresponding performance statistics tabulated in **Table 7-14**.

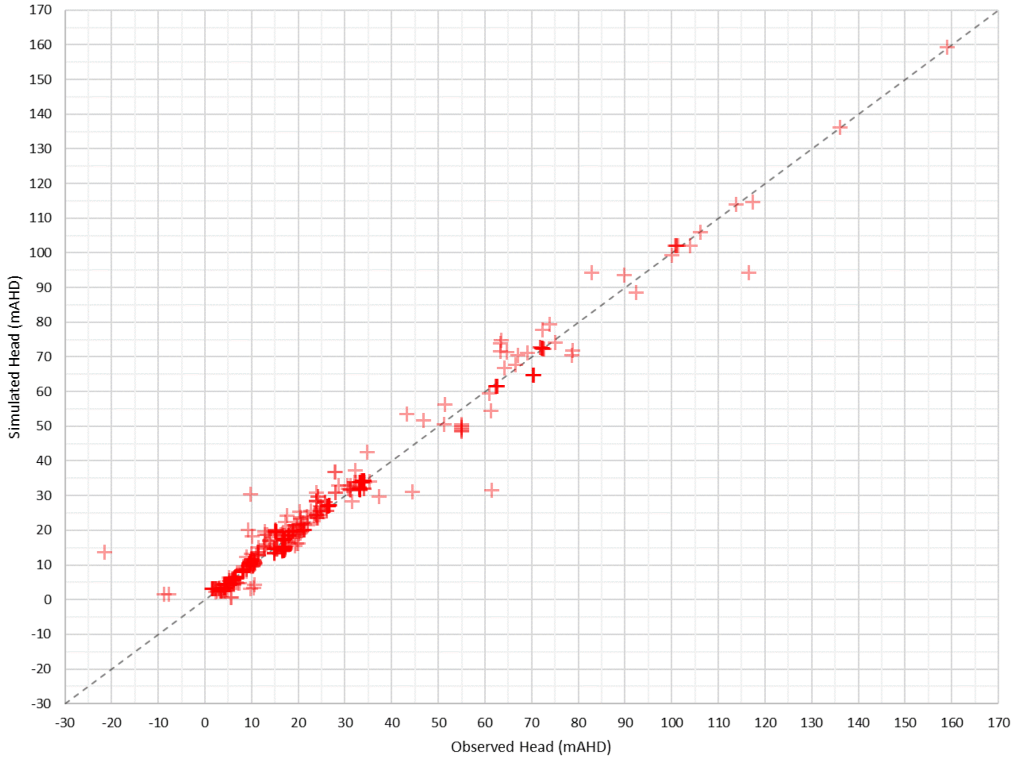
The scaled root mean square (SRMS) error for the transient calibration is 2.01%, where < 10% is the often-used criteria for acceptable model calibration (Barnett *et al.*, 2012) and is discussed further in **Section 7.9** and presented in **Attachment 10 (Table A10-4)**.

A comparison of the computed groundwater levels for the WMP Series Bores and select Landholder Bores with temporal measurements is also presented in **Attachment 8**. As demonstrated, the simulated groundwater levels compare very well for many observation bores and display an overall reasonably good trend for the extended below average rainfall conditions particularly in the surficial units (Cenozoic deposits and regolith) for most bores.

Head plots are presented for each model layer at the end of the transient calibration in **Attachment 13**. A map of average transient residuals to highlight the calibration performance across the model domain is presented in **Figure 7-9[a]**. A zoomed-in inset for comparison is presented in **Figure 7-9[b]**.

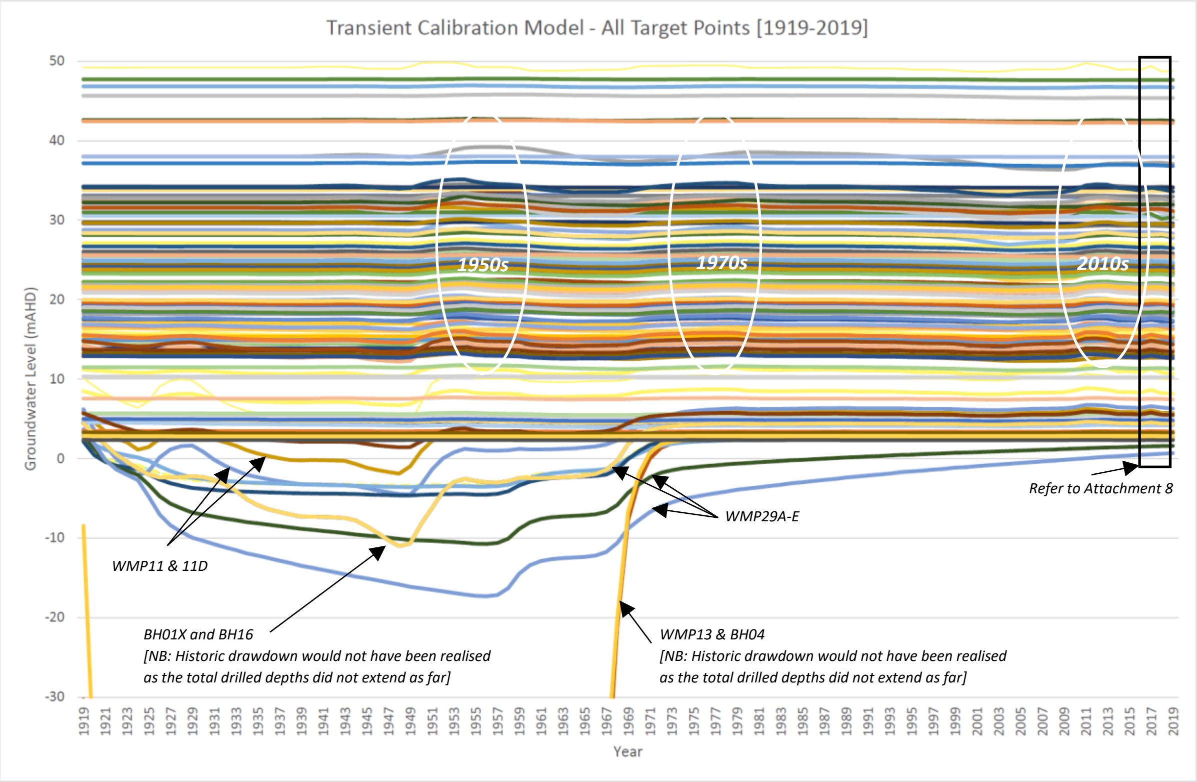


Graph 7-1
Steady State Calibration Model Simulated Versus Observed Scatter Plot



Graph 7-2
Transient Calibration Model Simulated Versus Observed Scatter Plot

For the purposes of the following commentary, a collation of all transient calibration model groundwater levels at the target points during the pre-calibration and calibration periods are presented on **Graph 7-3**.



Graph 7-3
Transient Calibration Model – All Target Points [1919-2019]

The following comments are made:

- The long term historical rainfall trends can be observed in the model outputs with changes in groundwater levels corresponding with above average rainfall periods around the 1950s, 1970s and 2010s (**Graph 3-1**).
- Pronounced drawdown is modelled as a result of the historic mine workings at Ogmore and Bowman at the following target points with recovery apparent in:
    - WMP29A-E;
    - WMP13;
    - WMP11 & WMP11D; and
    - Landholder Bores BH01X, BH04, BH16, BH20, BH24, BH25 and 187278.
- The long term historical below average rainfall trends can be observed in the model outputs as well as more recently (2018-2019) (**Attachment 8**) with changes in groundwater levels corresponding with below average rainfall periods around the 1960s, 2000s and approaching 2020.

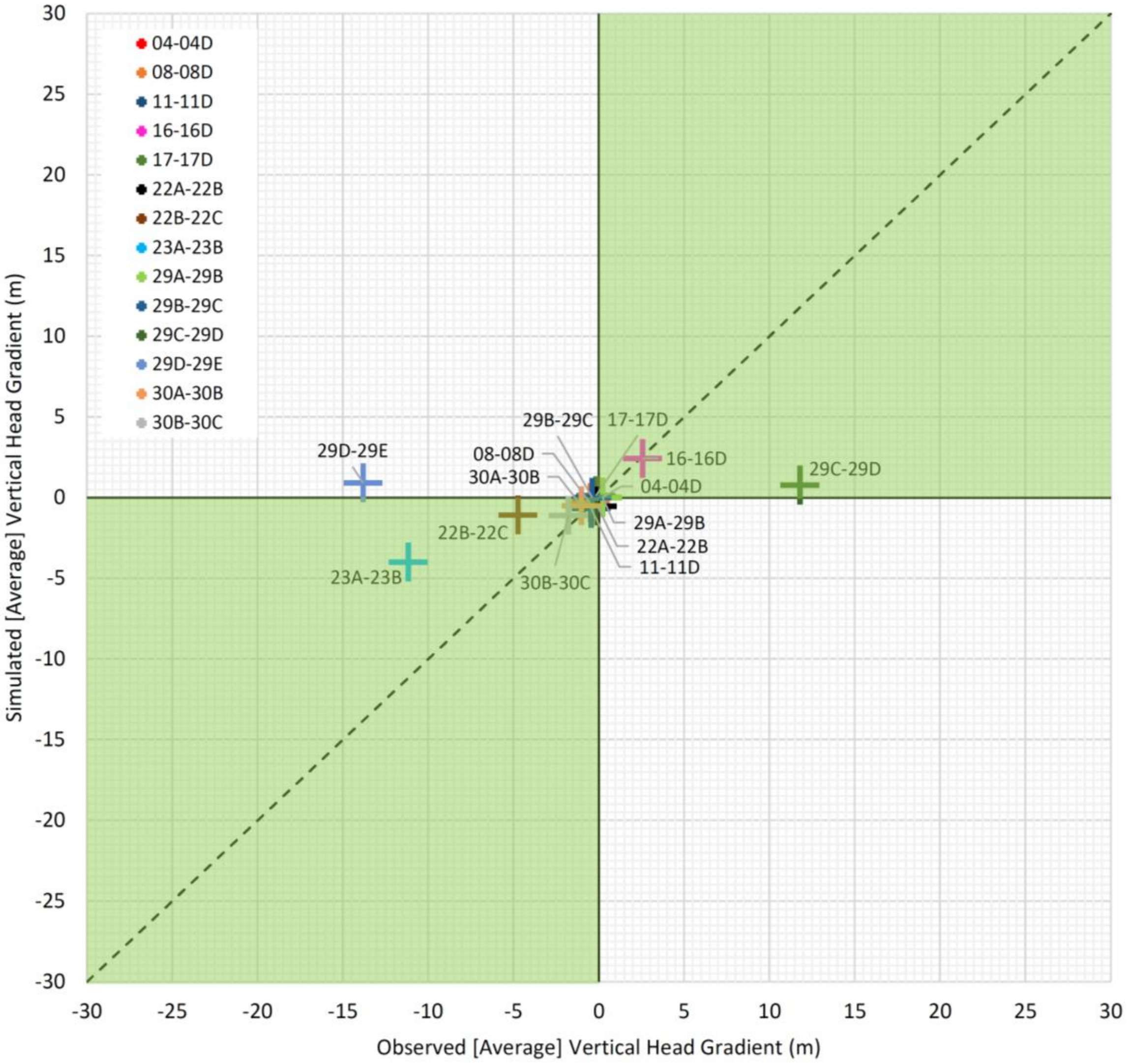
However, it must be noted that many of the groundwater targets at the Landholder Bores presented in **Graph 7-3** which are predicted to have extended well below 0 mAHD would not have been realised as the actual depth of the drill holes do not extend as far, or were not constructed at the time.

Vertical Head Gradients

A comparison of simulated and observed vertical head gradient differences at locations where observations are available at different elevations (i.e. shallow and deeper screen depths) is shown on **Graph 7-4**.

Overall, the vertical head gradients are generally consistent (e.g. upward [negative] simulated gradients = upward [negative] observed gradients; or downward [positive] simulated gradients = downward [positive] observed gradients) or if not, the gradient is very flat (i.e. near the graph centre point 0,0).

The clear exception being the observed and simulated gradients at the deepest groundwater bores near the historic mine workings at Ogmore (WMP29C, WMP29D and WMP29E) which as discussed above (**Graph 7-3**) are considered to be in recovery and therefore use of average values for determining gradients is less representative as the gradients would be expected to change with time. Furthermore, the model geometry is extrapolated and select layers pinched-out to the west where the Styx Coal Measures subcrop. Consequently, model layer assignment for the deep groundwater monitoring bores at WMP29C, WMP29D and WMP29E have been determined by a reasonable best fit rather than the actual depth of screens, for a spread of vertical pressure heads.



Graph 7-4
Comparison of Simulated [Average] and Observed [Average] Vertical Head Gradients

Extrapolated Residual Contour Mapping

For the purposes of identifying areas within the model domain where calibration performance could be targeted for ongoing improvement and/or targeted uncertainty analysis (**Section 8.12**), a series of extrapolated residual contour maps have been produced (**Figures 7-10[a] to 7-10[c]**). The results show that:

- In the Cenozoic deposits / regolith, modelled groundwater levels appear to be elevated (positive = over-predict) in the west coincidental with the rising topography and saddle point where Tooloombah Creek traverses between Mt Brunswick and Mt Mamelon.
- In the Styx Coal Measures, groundwater levels in the vicinity of the historic mine workings in the north show variations and therefore warrant consideration (**Section 8.10**) whilst to the east, the groundwater target at WMP10D appears to be a function of a SWL taken during drilling (prior to recovery). As discussed in **Section 5.4**, CQCPL has since installed WMP31 to the north-east (east of the fault) to validate the groundwater levels. Furthermore, given the presence of the Styx Coal Measures / Permian Measure interface, specific consideration is being made in the uncertainty (sensitivity) analysis to the east (**Section 8.11.3**).
- In the Permian Measures, the groundwater levels at WMP23B (at and below the underburden of the Styx Coal Measures) are not as high (i.e. negative = under-predict) as the datasets suggest. However, elsewhere in the vicinity of the CQC Project the groundwater levels are reasonably matched. Whilst modelled groundwater levels further afield (i.e. far east and north-east) appear to be elevated, the areas coincide with rising topography which are more a function of the mesh cell sizes.

7.7.5 Modelled Water Balance

A modelled water budget for the numerical groundwater model domain for the duration of the transient calibration model period A & B (Stress Periods 20 to 59) is presented in **Table 7-15**.

Table 7-15
Model Water Budget / Balance [Transient Calibration Period]

Component	Input (ML/day)	Output (ML/day)	Net (ML/day)
Recharge	51.457	0.0	51.457
Constant Head	19.064	1.502	17.562
Evapotranspiration	0.0	67.740	-67.740
River-Aquifer Interaction	1.386	3.234	-1.848
Storage	8.125	7.553	0.572*
Total	**80.033**	**80.030**	**0.003**

* A proportion of this storage relates to the recovery of historic workings.

Evapotranspiration is the greatest output (discharge) from groundwater system across the model domain with residual river-aquifer interaction of (-1.85 ML/day). For the purposes of analysis, **Figure 7-11** demonstrates that the higher fluxes are associated with the estuarine alluvium furthest north and the southern (Tertiary sediments) away from the immediate CQC Project and immediate surrounds.

As the depth to groundwater table across most of the Cenozoic sediments is generally greater than 10 m, the applied extinction depths to the surficial geological unit to 8 m is of no consequence.

Mass Balance Closure Error

The mass balance closure error statistics for the steady state and transient calibration model runs are presented in **Table 7-16** and achieves the generally accepted target threshold of <0.5% mass balance closure error (**Attachment 10**) **(Table A10-4)**.

Table 7-16
Steady State and Transient Calibration Model Mass Balance Closure Error Statistics

Model	Maximum Single Time Step Discrepancy	Final Cumulative Discrepancy	Maximum Cumulative Discrepancy
Steady State	<0.01%	<0.01%	<0.01%
Transient Calibration (including Pre-Calibration)	0.08%	0.01%	0.08%

7.7.6 Groundwater Connectivity

The inferred depth to groundwater table is presented in **Figure 5-4**, and consistent with the groundwater monitoring datasets (**Section 5**) and previous findings is generally at approximately 10 m and greater within ML 80187. With the exception of the deep-cut and incised watercourses, groundwater levels in lower lying topographic areas and shallow drainages are also typically greater than 8-10 m.

Independent comparisons and conservative connectivity analysis using the modelled groundwater table elevations with select reaches (and pools) of Deep Creek, Tooloombah Creek and Styx River in the vicinity of and downstream of the CQC Project have been made separately by Orange Environmental Pty Ltd (2020), WRM Water & Environment (2020) and Eco Logical Australia Pty Ltd (2020d) and are not presented herein. However, as discussed in **Section 8.12**, the numerical groundwater model cell discretisation uses an average elevation with each model mesh cell (utilising the detailed LiDAR datasets) and therefore does not skew the datasets by utilising the lowest LiDAR recorded elevations within each cell (i.e. along the invert of a watercourse). It is also recognised that in some cases, LiDAR datasets along watercourses may record the water surface where present and not the bathymetric depth, thus the lowest point in a reach (or pool) could be greater.

Nevertheless, groundwater-surface water interactions are modelled for the determination of changes to baseflow and/or enhanced leakage along defined watercourse reaches and are analysed in **Section 8.6**. Consistent with **Table 7-5**, the reaches are defined for separate assessment purposes to align with the *Water Act 2000*, with the modelled steady state volumes in the vicinity of and downstream of the CQC Project presented in **Table 7-17**.

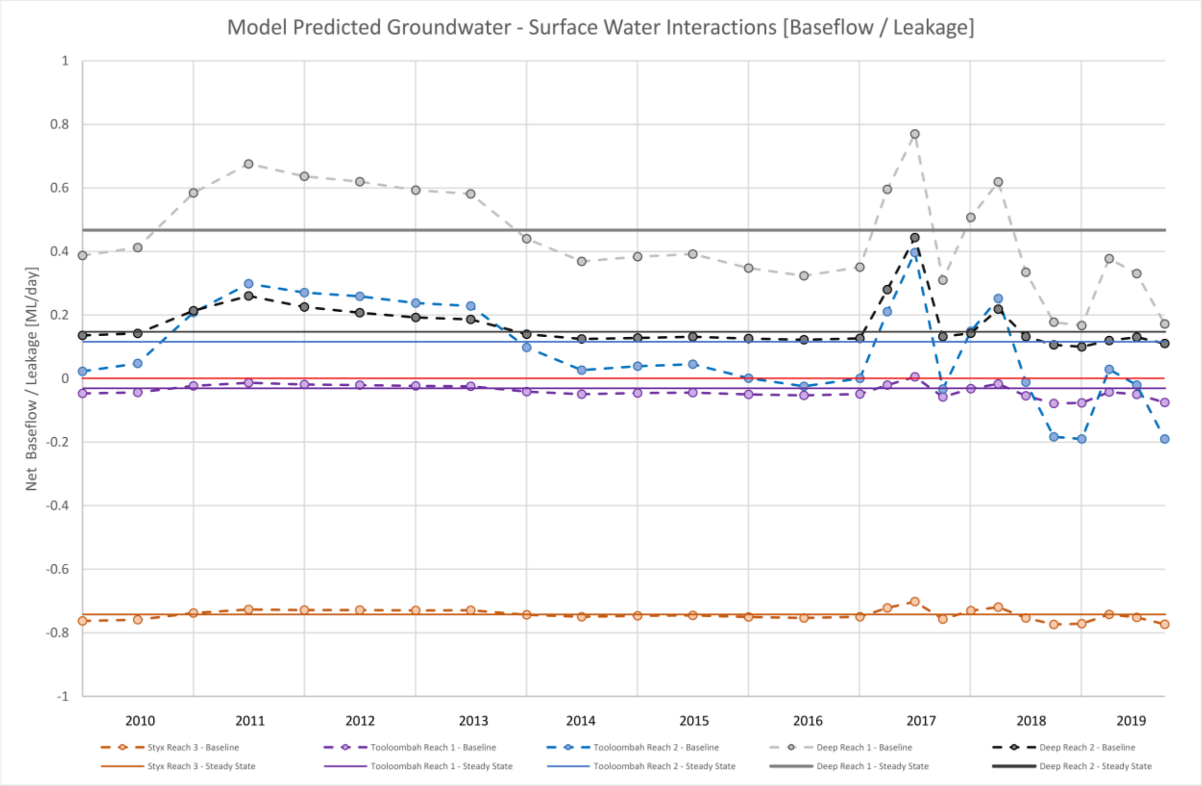
For refined analysis and comparison to the steady state value, the ranges modelled during the extended transient calibration period (2010 to 2019) are also presented on **Graph 7-5**. As demonstrated on the graph, the model response to higher rainfall / recharge periods is more pronounced in Deep Creek Reach 1 and 2 than other watercourses. Tooloombah Creek Reach 2 also shows rainfall/recharge responses and that during the extended below average rainfall conditions experienced in 2018-19, baseflow on average was net negative and therefore losing for periods.

It is important to note that the groundwater-surface water interaction predictions presented in this report are based on the groundwater model geometry and discretisation described in **Section 7.4**. For example, where longitudinal bed gradients are in fact steeper along a site-specific watercourse reach there may be areas where interflow over an extended period (and potentially groundwater discharge) occurs at times from up-reach areas. After surface expression, the water is subject to evaporative processes but also as the surface water flow then reports down-reach to lower bed gradients the conductance (and lower permeability) of the river bed (where finer silts/clays are deposited) are expected to maintain the surface water head profile whilst the phreatic (groundwater) surface at depth remains consistent with the overall longitudinal profile.

Table 7-17
Modelled Groundwater-Surface Water Interaction [Baseflow / Leakage]

Feature / Reach	Modelled (Steady State) Baseflow / Leakage [Net]	Modelled (Transient Calibration)* Baseflow / Leakage [Range]
Styx River / Upper Tidal Reach 3	-0.74 ML/day	-0.70 to -0.77 ML/day
Tooloombah Creek / Defined Watercourse Reach 1^	-0.03 ML/day	-0.08 to 0.01 ML/day
Tooloombah Creek / Defined Watercourse Reach 2	0.12 ML/day	-0.19 to 0.40 ML/day
Deep Creek / Defined Watercourse Reach 1	0.47 ML/day	0.17 to 0.77 ML/day
Deep Creek / Reach 2	0.15 ML/day	0.10 to 0.44 ML/day

^ Within identified tidal transitional zone.
* 2010 to 2019 Extended Calibration Period



Graph 7-5
Model Predicted Groundwater-Surface Water Interactions [Baseflow-Leakage]

Whilst stream gauging / datalogger records available during the calibration period did not record any rainfall events of significance due to the extended below average rainfall conditions, it should be noted that above average rainfall periods are reflected in the modelled groundwater levels during the extended calibration period to 2010 and beyond (**Graph 7-3**) and the responses shown in **Graph 7-5**.

Further discussions in relation to groundwater connectivity (i.e. groundwater quality) is presented in **Section 5.5.7** and opportunities for future model validation is discussed in **Section 10.9**.

7.8 MODEL VALIDATION

As the CQC Project is yet to commence, naturally model validation of predicted changes (i.e. mine inflows) against corresponding datasets is unable to be carried out.

However, as described in **Section 7.5.6** historic mining within the model domain provides a useful history-matching check of the potential scale, nature and recovery of the effects of past operations in the pre-calibration runs.

Post model construction and calibration, additional datasets have since been made available through ongoing investigation activities undertaken by CQCPL in 2020, and comparisons are made below in support of the model conceptualisation to provide further confidence in the reliability of the improved numerical groundwater model.

7.8.1 Post Model Calibration Pool Survey Levels (ToGS01, To2, DeGS01, De2Pool1, De3)

As discussed in **Section 7.7.1**, despite the installation of stream flow gauges in Tooloombah Creek and Deep Creek (**Section 3.3.3**), there were no flow events recorded at the time of cut-off for model calibration datasets which was a known/planned limitation, recognising that the numerical groundwater model would be subject to robust uncertainty analysis (**Sections 8.11 and 8.12**) and opportunities for future review and validation (**Section 10.9**).

However, post the January-February 2020 rainfall events, detailed survey of pool level elevations at five (5) separate locations along the reaches of Tooloombah Creek and Deep Creek were completed by CCS Surveys Pty Ltd (2020). The survey has provided the opportunity to compare the recorded pool levels (mAHD) in May 2020 with the numerical groundwater model elevations (mAHD) at the nearest RIV cells at the end of calibration in Layer 2 of the model; the applied RIV cell stages in Tooloombah Creek and Deep Creek; and the zero stage elevation for the additional model sensitivity run completed, and the results presented on **Graphs 7-6 and 7-7**. It is noted that **Graph 7-6** is shown at the same scale as **Graph 7-2** to demonstrate the data fit is validates well. At a zoomed-in scale, **Graph 7-7** shows for:

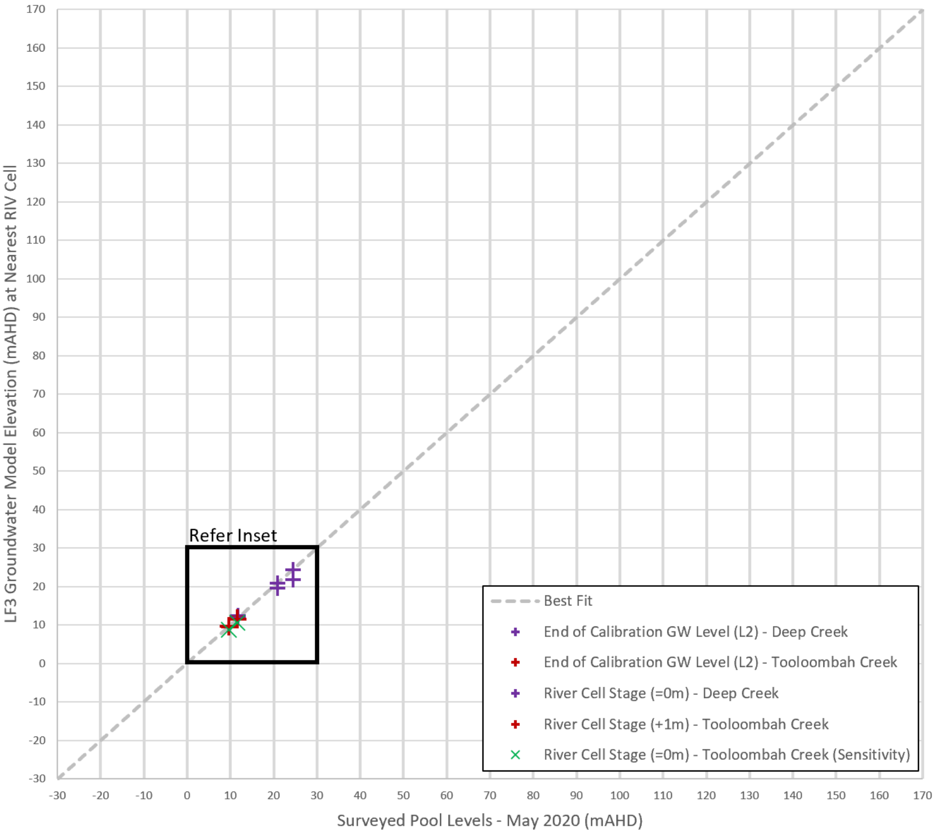
- Tooloombah Creek: the applied RIV cell stage (+1 m) is a good fit, whereas the zero stage elevation applied (recommended by the peer review as a model sensitivity run [**Section 8.11.6]**) is lower; and
- Deep Creek: the approximate 2 m differential is not unexpected at the higher topographic locations, recognising that the groundwater model groundwater level prediction is at end of calibration period corresponding with extended dry period (Sept-Oct 2019) (and dry observation records), versus surveyed pool levels recorded in May 2020, post the January-February 2020 rainfall events and is consistent with the applied RIV cell stage (0 m).

The survey levels have also been used to tie the gauging station streamflow records since installation to mAHD and are shown on **Graphs 5-1 and 5-2** for relative comparison with groundwater levels recorded at WMP05 (Qa) and WMP04 (Qpa).

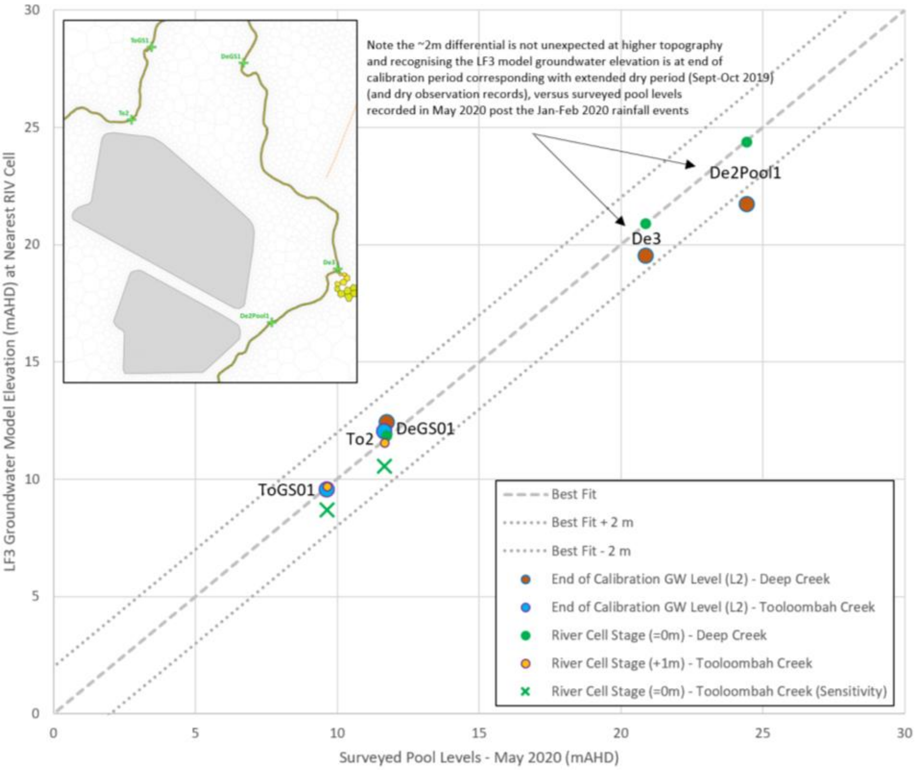
7.8.2 Post Model Calibration Back Creek Group North-East Groundwater Level (WMP31)

Following model calibration, WMP31 was installed in the Permian Back Creek Group (**Section 5.1.3**). The initial datasets available (**Attachment 8; Graph A8-54**) show that groundwater levels/pressures have been recovering since installation to approximately 33-35 mAHD in February 2020.

This presented the opportunity to compare the recorded groundwater levels with the numerical groundwater elevations (mAHD) at the model cell. The zonal steady-state Layer 2 head (mAHD) at the numerical model cell at the approximate location of WMP31 was 35.65 mAHD, demonstrating again a good match.



Graph 7-6
Post Model Calibration Pool Survey Levels Validation



Note the ~2m differential is not unexpected at higher topography and recognising the LF3 model groundwater elevation is at end of calibration period corresponding with extended dry period (Sept-Oct 2019) (and dry observation records), versus surveyed pool levels recorded in May 2020 post the Jan-Feb 2020 rainfall events

Graph 7-7
Post Model Calibration Pool Survey Levels Validation [Inset Zoom]

7.8.3 Post Model Construct Fault Interface Validation (RDK7-RDK12)

In May 2020, following the installation and review of several geological drill logs (RDK7-RDK12), CQCPL compiled a memorandum titled *Fault Investigation – Eastern Styx Coal Measures* (CQCPL, 2020b). Relevantly, the actual fault plane was intersected during drilling conducted at RDK10. The drill core appears to be steeply dipping Styx Coal Measures but recovered a change in character to those seen to the east (a Permian intersection) (CQCPL, 2020b).

As shown on **Figure 7-12**, the location of drill hole RDK10 correlates well with the Styx Coal Measures and Permian Back Creek Group interface used in the numerical groundwater model construction, thus validating the conceptual extension of the fault structure to the south.

The results of the geological drill logs (RDK7-RDK12) were also used in support of the subsequent installation of WMP21B in the Styx Coal Measures (west of the fault) and to the north of the CQC Project open cut extent.

7.9 MODEL CONFIDENCE

The Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012) prescribe three classes of groundwater models (Class 1, Class 2 or Class 3) in order of increasing confidence based on key indicators such as available data, calibration procedures, consistency between calibration and predictive analysis and level of stresses.

The previous numerical groundwater flow model (CDM Smith, 2018) was described as a Class 1 model despite meeting some of the Class 2 requirements.

The overall target model confidence level classification for the improved CQC Project numerical groundwater model is Class 2, and as demonstrated in **Attachment 10 (Tables A10-1 to A10-5)**, has been largely achieved and exceeded for several key criteria (based on Table 2-1 of Barnett *et al.*, 2012), most notably:

- Groundwater head observations and drill hole logs are available across the model domain (**Sections 5.1-5.4**), and with a reasonable spatial coverage in the vicinity of the CQC Project and surrounds.
- Aquifer testing datasets are available to define key parameters for aquifers (**Section 5.6**).
- Scaled RMS (SRMS) errors (3.49% and 2.01%) and mass balance (maximum cumulative) closure errors (<0.01% and 0.08%) for steady state and transient model runs are acceptable and are calibrated to heads (**Sections 7.7.4 and 7.7.5**)
- The length and temporal discretisation of the forward predictive model (i.e. 18 years, monthly) is comparable to the length of the transient calibration period (2010-2019), in addition to the pre-calibration model variant (from 1919 to 2010) which includes approximately 45 years of historic mining operations in the Styx Coalfield.

Despite being a proposed mining area where groundwater systems are generally of limited potential, there are substantial datasets to draw upon which continue to be augmented with ongoing baseline data collection by CQCPL to satisfy regulator guideline requirements.

However, the area has been naturally limited by a lack of flow/flux (i.e. stream flow) data, to calibrate against, primarily as extended below average rainfall conditions have occurred since early 2017 as shown on the cumulative rainfall residuals [**Attachment 8**]) and that other drainage features in the Deep Creek catchment are generally ephemeral in nature.

As demonstrated in **Attachment 10**, the overall confidence level classification is considered to be Class 2, and capable of a number of specific uses, and most relevantly:

- is capable of providing estimates of dewatering requirements for mines and excavations and the associated impacts;
- is capable of providing impact predictions of proposed developments in medium value aquifers;
- is capable of predicting long-term impacts of proposed developments in low value aquifers; and
- is capable of evaluating to inform management of medium risk impacts.

Therefore, in accordance with the Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012), the improved numerical groundwater flow model is considered fit for purpose to meet the scope and objectives as outlined in **Section 1.2**.

8.0 NUMERICAL GROUNDWATER MODEL – FORWARD PREDICTIONS, IDENTIFIABILITY ANALYSIS AND UNCERTAINTY ANALYSIS

The indicative mine layout for the CQC Project as provided by CQCPL on 31 January 2020 is shown on **Figure 8-1**.

8.1 MINING SCHEDULE / PROGRESSION

An indicative mining schedule proposed for the CQC Project is summarised in **Table 8-1**, as provided by CQCPL in 2019. The corresponding indicative mine plan (periodic) progression and backfill (annual) sequence is shown on **Figure 8-2**.

The mining schedule has been used based on an estimated monthly mine progression sequence generally consistent with the mine planning details for the schedule simulation and waste rock dump and rehabilitation designs developed by Alpha-Mine Planning 4U (2018a and 2018b) and updates presented in the designs by Alpha-Mine Planning 4U (2020).

Table 8-1
Indicative Mining Schedule

Period (Year)*	Open Cut Mine Sequence [**Figure 8-1**]	Proposed Works / Activities				
		Construction	Pre-Stripping	Mining	Backfilling	Rehabilitation
1 (1 July 2020 – 30 Jun 2021)	Open Cut 2	✓	✓	✓		
2 (1 July 2021 – 30 Jun 2022)	Open Cut 2	✓	✓	✓		
3 (1 July 2022 – 30 Jun 2023)	Open Cut 2		✓	✓	✓	✓
4 (1 July 2023 – 30 Jun 2024)	Open Cut 2		✓	✓	✓	✓
5 (1 July 2024 – 30 Jun 2025)	Open Cut 2		✓	✓	✓	✓
6 (1 July 2025 – 30 Jun 2026)	Open Cut 2		✓	✓	✓	✓
7 (1 July 2026 – 30 Jun 2027)	Open Cut 2		✓	✓	✓	✓
8 (1 July 2027 – 30 Jun 2028)	Open Cut 2	✓	✓	✓	✓	✓
9 (1 July 2028 – 30 Jun 2029)	Open Cuts 1 & 2	✓	✓	✓	✓	✓
10 (1 July 2029 – 30 Jun 2030)	Open Cuts 1 & 2	✓	✓	✓	✓	✓
11 (1 July 2030 – 30 Jun 2031)	Open Cuts 1 & 2		✓	✓	✓	✓
12 (1 July 2031 – 30 Jun 2032)	Open Cuts 1 & 2		✓	✓	✓	✓
13 (1 July 2032 – 30 Jun 2033)	Open Cut 2		✓	✓	✓	✓
14 (1 July 2033 – 30 Jun 2034)	Open Cut 2		✓	✓	✓	✓
15 (1 July 2034 – 30 Jun 2035)	Open Cuts 1 & 2		✓	✓	✓	✓
16 (1 July 2035 – 30 Jun 2036)	Open Cuts 1 & 2		✓	✓	✓	✓
17 (1 July 2036 – 30 Jun 2037)	Open Cuts 1 & 2			✓	✓	✓
18 (1 July 2037 – 30 Jun 2038)	Open Cuts 1 & 2			✓	✓	✓
Mine Closure (1 July 2038 – 30 Jun 2039)					✓	✓

Source: CQCPL (2019).
*Assumed CQC Project commencement date is 1 July 2020 for model purposes but is subject to receipt of all relevant statutory approvals.

ROM coal production would ramp up during the life of the CQC Project from the initial development stage of approximately 2 million tonnes per annum (Mtpa) to approximately 4 Mtpa, with a period of up to approximately 10 Mtpa ROM coal, producing in the order of 8.4 Mtpa product coal.

It is however recognised that over the life of the CQC Project the mining schedule and sequence may vary to take account of: localised geological features; mine economics; market volume requirements; detailed mine design considerations; and adaptive management.

8.2 PREDICTIVE MODEL RUNS / APPROACH

8.2.1 Initial Conditions

As described in **Section 7.6** and **Table 7-9**, initial conditions are based on the end of the calibration period (Transient Calibration B) in September 2019. For the intervening period between the calibration period end and mining commencement (assumed 1 July 2020 for the purposes of modelling), a monthly transient prediction monthly prelude period (**Stress Periods 60-68**) has been adopted for continuity in the transient prediction model runs.

8.2.2 Stress Period Lengths

As provided in **Table 7-10**, the stress period lengths for the predictive model range from monthly (for mine prediction and mine closure) to annual (for post-mining), five yearly (to 100 years post mining) and 400 years (for long-term post-mining recovery).

The time horizons for prediction is not excessive when compared with the length of the pre-calibration and calibration periods described in **Section 7.6.1**.

8.2.3 Climate

Climate is kept constant in the forward prediction model runs to allow the output analysis to isolate from modelled mining effects for impact assessment purposes. Episodic flood (recharge) events which are recognised in the historic climate variability are also not specifically applied in the forward prediction model and therefore allows for conservative assessment.

Climate change predictions are considered in the uncertainty analysis (as a sensitivity scenario) and is discussed in **Sections 8.11.3 and 8.11.5**.

8.3 PREDICTIVE MODEL – APPLICATION FOR KEY PROCESSES

The open cut mine sequencing and methods are described in detail in Chapter 3 of the SEIS (CDM Smith, 2018). In summary, as presented in **Table 8-1**, the general sequence of activities includes construction, pre-stripping, mining, backfilling and rehabilitation.

For the purposes of numerical groundwater modelling, as construction and pre-stripping activities are predominantly at and/or above the existing ground surface level (and/or groundwater table [i.e. phreatic surface]), the vegetation clearance and soil stripping/stockpiling processes are not simulated. All open cut mining (pit excavation), backfilling (including in-pit emplacement) and final landform design surfaces (including out-of-pit emplacement) are simulated and described in the following sub-sections.

No underground mining operations are proposed as part of the CQC Project. Therefore, surface subsidence caused by underground goafing would not occur.

Any residual subsidence associated with dewatering and depressurisation of groundwater from the surrounding formations at the CQC Project (i.e. in the Early Cretaceous Styx Coal Measures) and to a far lesser extent in the overlying Quaternary sediments would be negligible and immeasurable for off-site open cut effects, and therefore is not considered any further.

Given the generally limited groundwater use by surrounding landholders, and available datasets at BH01X and BH16, adjacent to the existing private landholder bore in use (BH20), private landholder usage has not been explicitly applied in the numerical groundwater model, however is considered in the uncertainty analysis (**Section 8.11.4**).

8.3.1 Pit Excavation – Annual Mine Progression and Depths

Active open cut mining areas are simulated using drain cells with the invert elevation guided by model layer geometry (i.e. basal coal seam layers), based on the geological model and cross-sections (**Sections 7.3 and 4.2.2**) and the mine progression plans provided by CQCPL (2019) (**Figure 8-1**).

The deepest drain depths applied within the proposed open cut extents are in the northern open cut (Open Cut 2) toward the east at approximately -146 mAHD to -152 mAHD, and in the southern open cut (Open Cut 1) in the north-east at approximately -123 mAHD.

Advanced dewatering, if required during the life of the CQC Project, would be temporary and, whilst external to the advancing open cut sumps, would be installed inside the proposed open cut footprint as sacrificial bores/pumps. Therefore, besides the drain cells applied to the advancing open cut, no other drain cells are modelled beyond the proposed open cut extents. Thus, whilst the timing for the effect of drawdown may change, the maximum predicted drawdown predictions would remain unchanged, and there would be no additional development footprint for the dewatering infrastructure.

8.3.2 Initial Out-of-Pit Emplacement of Waste Rock and Coal Rejects – Extent of Landforms and Hydraulic Properties

Annual mine progression plans (including initial out-of-pit waste rock emplacements) were provided by CQCPL and updates presented in the designs by Alpha-Mine Planning 4U (2020).

Coal rejects (including coarse rejects and filter press tailings) would initially be trucked to the out-of-pit waste rock emplacements for blending with overburden spoil, prior to disposal in-pit once the open cut mining areas are developed and is considered in **Section 8.3.4**. Targeted groundwater (seepage) monitoring is proposed and is described separately in **Section 10.3.1**.

It is noted that the topography of the out-of-pit waste rock emplacement areas changes during the operational life of the CQC project, with backfilling of all voids in the latter year(s) with approximately 46.9 Mbcm and 99 Mbcm of ex-pit spoil allocated for re-handling in Open Cut 1 and Open Cut 2, respectively. Given the temporary nature of these out-of-pit waste rock emplacements that are re-handled, the elevations of the backfill spoil emplacements were not modelled beyond the final rehabilitated landform (**Section 8.3.6**), despite the temporary differences in elevations. This is considered to be of no material consequence to the numerical groundwater model predictions during mining as the groundwater table would generally be in excess of tens of metres deep during the operational life and would be lower due to the advancing open cut mining areas.

8.3.3 In-pit Backfilling of Waste Rock – Timing, Hydraulic Properties and Enhanced Recharge

Annual mine progression plans (including in-pit backfill scheduling) were provided by CQCPL and updates presented in the designs by Alpha-Mine Planning 4U (2020).

The backfilling process is simulated by applying Time-varying Material (TVM) properties to reflect the changes in the host rock properties (pre-mining) to reflect the backfill spoil (broken, less consolidated rock), and was applied generally consistent with the backfill schedule provided. Minor adjustments were made to align with the incremental period plot (drain) scheduling (based on a monthly stress period) and final landform design.

The adopted hydraulic properties (higher permeabilities) applied to spoil were made consistent with the conceptualisation (**Table 6-4**) and summarised in **Table 8-2** below.

Table 8-2
Application of TVM Parameters – Spoil Hydraulic Properties

Higher Permeabilities					
K_H	K_H/K_V	S_y	S_s [1/m]	Enhanced Infiltration (Groundwater Recharge)	Evapotranspiration (Depth and Maximum Rate)
1 m/day	1	0.2	1.3×10^{-5}	5% of Rainfall	Unchanged

In addition to the TVM properties applied, a higher infiltration rate (enhanced rainfall recharge in spoil) was accommodated in the groundwater model by assigning a higher rainfall recharge percentage (i.e. 5% of rainfall). The properties relevantly consider Hawkins (1998) and note that mine waste rock material is typically broken rock with lesser clay/fine components which might otherwise be found in unconsolidated Quaternary units deposited by fluvial processes (thus an enhanced infiltration component is applied). It is also noted that the evapotranspiration rates and depths from the surface remained unchanged.

8.3.4 In-pit Emplacement of Coal Rejects – In-pit Locations

Coal rejects (including coarse rejects and filter press tailings [dewatered fine rejects]) would be disposed of in-pit as the open cut mining areas are developed and blended with overburden waste rock (bulk spoil). Emplacement activities would be conducted in accordance with a Mineral Waste Management Plan.

As the coal rejects are blended with the bulk spoil (some 745 Mbcm in total), the total proportion of coal rejects (approximately 10 Mt in total during the operational life) would not be expected to have a considerable effect on the hydraulic properties already applied to the spoil in the groundwater model simulation (**Section 8.3.3**) and therefore is left unchanged.

8.3.5 Water Storage Dams and Water Releases

As shown on **Figure 8-1**, a number of water storage dams are proposed at the CQC Project including mine water supply and environmental dams. Importantly, it is considered that such dams would be designed and constructed to minimise leakage/seepage through being engineered (e.g. keyed in) accordingly and would therefore not result in any significant additional groundwater recharge sources, recirculation or enhanced recharge to the open cut mining areas and/or backfill spoil which are simulated (**Sections 8.3.1 and 8.3.3**).

The effects of controlled water releases (and uncontrolled spillway discharges) on downstream watercourses are assessed separately by WRM Water & Environment (2020) and have not been included in the numerical groundwater model (i.e. changes to stage elevations downstream), however is recognised for the purposes of future groundwater model validation when comparing predicted changes to baseflow/leakage.

8.3.6 Final Landform Design – Final Elevations and Catchment Excision

Final landform designs were provided by CQCPL and updates presented in the designs by Alpha-Mine Planning 4U (2020). Corresponding progressive rehabilitation plans are presented in Xenith Consulting (2020).

With the exception of the two out-of-pit waste rock emplacement areas, the final landform (after backfilling) generally reflects the pre-mining ground surface levels across the mined area. The indicative final landform design surface (referred as LF3) is shown on **Figure 8-2**. As described in **Section 8.3.3**, the backfilling process was simulated in the numerical groundwater model with changes to hydraulic properties applied to the in-pit backfill spoil emplacement areas with elevations reflecting the backfilled final landform design surface.

The elevated final rehabilitated landforms beyond the in-pit backfill spoil emplacement areas have been simulated in Layer 1 of the numerical groundwater model with elevations of up to approximately 75 m above the pre-mining ground surface levels. The following characteristics have been applied to such areas:

- higher permeability of the spoil (broken, less unconsolidated rock);
- higher infiltration rate (enhanced rainfall recharge in spoil); and
- higher evapotranspiration surface (absolute), however the evapotranspiration rates and depths from the surface remain unchanged.

While surface water catchment diversions and changes to local catchment runoff post-mining are not included in the numerical groundwater model (when determining baseflow/leakage changes), the excised catchment runoff estimated by WRM Water & Environment (2020) in combination is relevantly noted.

8.4 PREDICTIVE MODEL – GROUNDWATER TAKE / INFLOWS

The model predicted groundwater take / direct inflows to the open cut mining areas are presented in **Table 8-3** as daily averages for an average annual period. The nearest lateral distance between the extent of Open Cut 1 and Open Cut 2 to Deep Creek and Tooloombah Creek respectively is approximately 150 m. No direct water take is proposed from either watercourse.

It is important to note that the modelled average inflow predictions are for groundwater take accounting purposes and that the actual groundwater inflows reporting to the in-pit sumps (and therefore handled in the site water balance) may be less (or instantaneously more) than those predictions due to a number of factors including potentially enhanced evaporation at the highwall face, actual mine progression and the backfilling sequence (including rate of wetting-up of backfill spoil), etc.

The model predicted inflows do not account for direct rainfall or surface water runoff held in storage, nor any pumped water transfers if held in-pit from time to time.

The model predicted groundwater take / direct inflows are also presented on **Graph 8-1**, as daily averages for operational life of the CQC Project (2020-2038) for quarterly intervals based on the configured groundwater model mine sequence.

Predicted inflows steadily increase in Open Cut 2 (i.e. the North Pit) during the first 2 to 3 years of the CQC Project as the pit is developed and depth increases to the east. Predicted inflows remain generally between 1.0 ML/day and 1.2 ML/day for the next three years and gradually reduces to approximately 0.6 ML/day before the commencement of mining in Open Cut 1 (the South Pit).

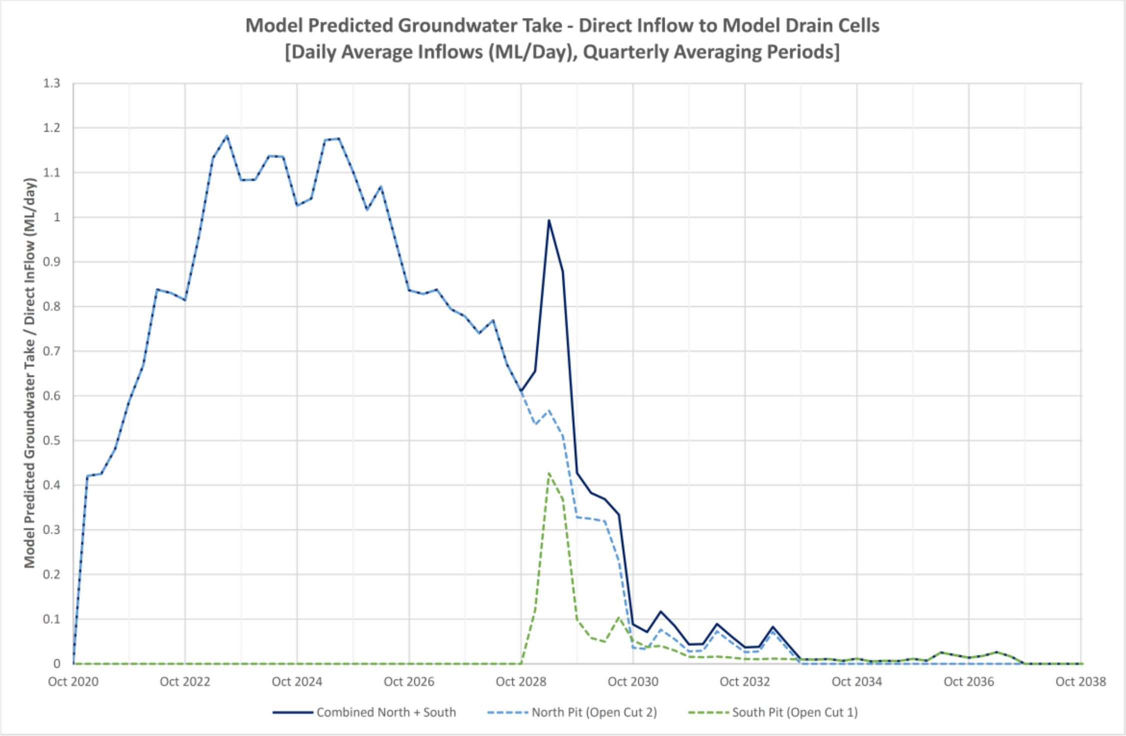
Combined inflows in Open Cut 1 and Open Cut 2 during the concurrent mining period then peaks at just below 1.0 ML/day before again steadily reducing to negligible inflows for the final years of the CQC Project as the backfilled spoil in the previously mined (down-gradient to the north and east) areas are recharged and recovering.

For the operational life of the CQC Project (2020-2038), the configured groundwater model predicts an average groundwater take of approximately 0.5 ML/day.

Table 8-3
Model Predicted Groundwater Take – Direct (Daily Average) Inflows to Open Cut Mining Areas

Period (Year)*	Open Cut Mine Sequence **[Figure 8-1]**	Daily Average Inflows for Average Annual Period [ML/day]		
		Open Cut 1	Open Cut 2	Total (Combined)
1 (1 July 2020 – 30 Jun 2021)	2	-	0.21	0.21
2 (1 July 2021 – 30 Jun 2022)	2	-	0.64	0.64
3 (1 July 2022 – 30 Jun 2023)	2	-	0.93	0.93
4 (1 July 2023 – 30 Jun 2024)	2	-	1.12	1.12
5 (1 July 2024 – 30 Jun 2025)	2	-	1.09	1.09
6 (1 July 2025 – 30 Jun 2026)	2	-	1.09	1.09
7 (1 July 2026 – 30 Jun 2027)	2	-	0.86	0.86
8 (1 July 2027 – 30 Jun 2028)	2	-	0.77	0.77
9 (1 July 2028 – 30 Jun 2029)	1, 2	0.14	0.60	0.73*
10 (1 July 2029 – 30 Jun 2030)	1, 2	0.14	0.37	0.51
11 (1 July 2030 – 30 Jun 2031)	1, 2	0.06	0.09	0.15
12 (1 July 2031 – 30 Jun 2032)	1, 2	0.02	0.05	0.07
13 (1 July 2032 – 30 Jun 2033)	2	0.01	0.04	0.06*
14 (1 July 2033 – 30 Jun 2034)	2	0.01	0.01	0.02
15 (1 July 2034 – 30 Jun 2035)	1, 2	0.01	<0.01	0.01
16 (1 July 2035 – 30 Jun 2036)	1, 2	0.01	<0.01	0.01
17 (1 July 2036 – 30 Jun 2037)	1, 2	0.02	<0.01	0.02
18 (1 July 2037 – 30 Jun 2038)	1, 2	<0.01	<0.01	<0.01

* Note: Totals do not equate due to rounding of quarterly average volumes.



Graph 8-1
Model Predicted Groundwater Take – Direct (Daily Average) Inflow to Modelled Drain Cells [2020-2038]

8.5 PREDICTIVE MODEL – MAXIMUM GROUNDWATER DRAWDOWN INFLUENCE / DEPRESSURISATION

Modelled changes in predicted groundwater levels have been extracted from the numerical groundwater model runs during the mine progression and are presented through time in spatial (contour maps), tabulated (at and below specific features) and graphical (hydrograph) form.

For the purposes of assessment, contour maps are presented for the following time periods (**Attachment 14**):

- After three (3) years of commencement of mining (to align with the indicative review timeframes prescribed for Underground Water Impact Reports [UWIRs] in Qld[xviii]) [*Model Stress Period 106*];
- After approximately 10 years of mining (i.e. mid-point of the CQC Project timeframe) [*Model Stress Period 190*]; and
- At end of open cut mining (prior to final backfill) [*Model Stress Period 284*].

A maximum spatial drawdown contour map is also presented which is a collective maximum for the simulation period, for the purposes of conservative assessment.

Drawdown contours are shown at regular intervals and are shown clearly in **red** for the 2 m drawdown extent which apply to unconsolidated aquifers (i.e. Layers 2, 3 and 4, including Quaternary Alluvium, Quaternary Pleistocene Alluvium and regolith).

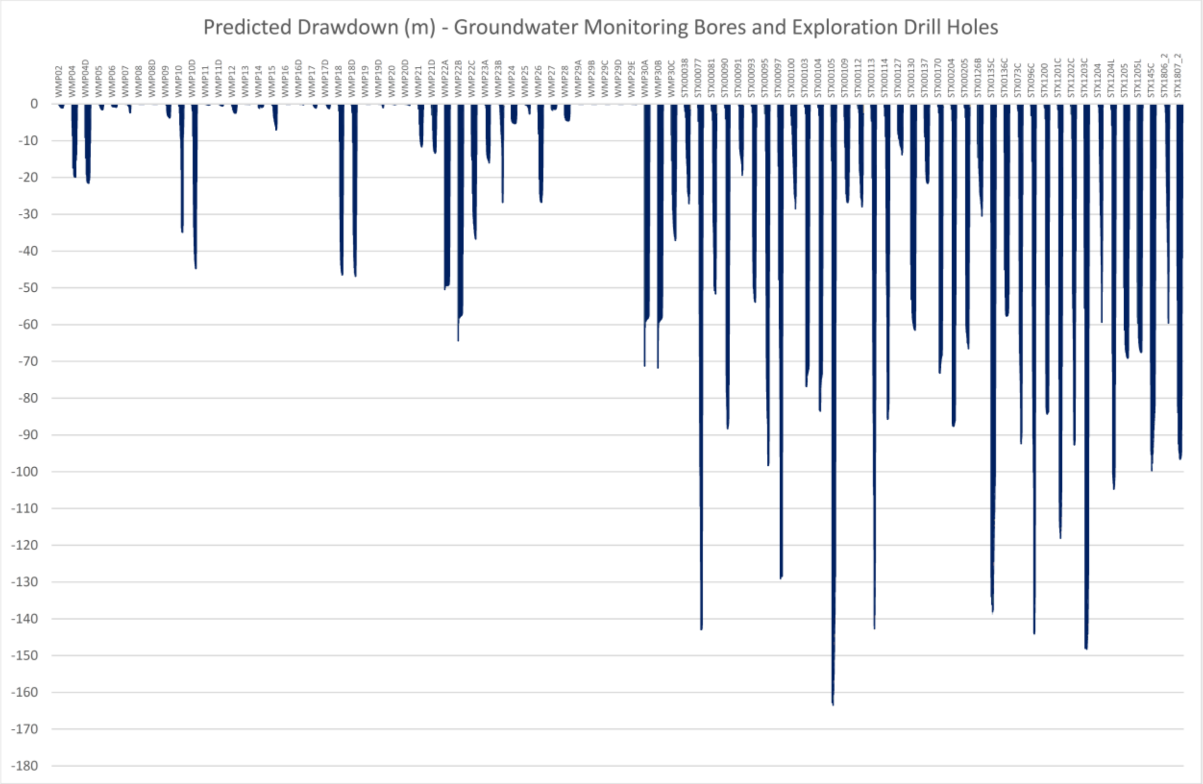
These drawdown contours are shown in accordance with the bore trigger thresholds defined in the *Water Act 2000* to identify any bores that are likely to be impacted and would require further bore assessment and are discussed in **Section 8.7.1**. Note however the lower of the two bore trigger thresholds is shown in all plots (i.e. despite only 5 m applying to the consolidated aquifers). The predictive model results indicate that with the exception of several bores in the vicinity of the CQC Project, drawdown effects at private landholder bores would be negligible and/or immeasurable to nil.

Further to the above, predicted drawdown at all groundwater monitoring network bores and historic exploration drill holes (many which are located within the proposed open cut extent) is presented in **Graph 8-2**. As demonstrated, substantial drawdown occurs within the proposed open cut extent, and the surrounding network of groundwater monitoring bores provide varying levels of change to allow the development of appropriate triggers for investigation and is discussed separately in **Section 10.1.10**.

Head plots for select model layers (i.e. Upper: Layers 2 and 3; Middle: Layers 5 and 8; Lower: Layers 11 and 12) are also presented in **Attachment 15** for comparison with the drawdown contour maps, and includes the post-mining recovery plots for Model Stress Period 300 (i.e. approximately 5 years post-mining) and Model Stress Period 320 (long-term recovery). The predictive (recovery) model results are discussed separately in **Section 8.9**.

For the purposes of the following analysis, four (4) spatial drawdown contour maps are presented at a zoomed-in scale on **Figure 8-3[a-d]** as follows:

- Layer 8 (Styx Coal Measures) – After three (3) years of commencement of mining.
- Layer 3 (Cenozoic deposits (lower) / regolith) – After approximately ten (10) years of mining.
- Layer 2 (Cenozoic deposits / regolith) – At end of open cut mining.
- Layer 12 (Back Creek Group) – At end of open cut mining.



Graph 8-2
Model Predicted Groundwater Drawdown – Groundwater Monitoring Bores and Exploration Drill Holes

8.5.1 Styx Coal Measures

Figure 8-3[a] shows that the maximum groundwater level drawdown in the Styx Coal Measures during the first three (3) years are largely contained in the north-western area of Open Cut 2. This allows for adaptive monitoring of the gradual propagation of groundwater drawdown and depressurisation in the Early Cretaceous sequence in advance of mining further east (**Section 10.1.7**).

As shown in **Attachment 14**, the maximum predicted groundwater level drawdown is largely contained within the Styx Coal Measures (Layers 6, 8 and 10), extending to lesser magnitudes (i.e. <2 m) beyond the open cut extent up to approximately 3.5 km in the north, 5 km in the north-east (at depth), and 3 km in the south-east. Drawdown propagation in the overburden (Layer 5) and underburden (Layer 11) of the Styx Coal Measures beyond the open cut extent toward the north-east and west respectively is predicted to be less, which correspondingly reduces indirect groundwater take in the surficial geology discussed further below and separately in relation to baseflow/leakage in **Section 8.6**.

8.5.2 Quaternary Pleistocene Alluvium / Regolith

As shown by the 2 m drawdown contour in Layers 2 and 3 (**Figures 8-3[b&c] and Attachment 14**), the predicted groundwater level drawdown in the surficial geology (i.e. Quaternary Pleistocene Alluvium/ Regolith), where saturated beyond the open cut extent, extends approximately 3 km to the north/north-west of Open Cut 2 at its nearest point and approximately 3 km to the south/south-east of Open Cut 1 at its nearest point. As the open cut mining operation progresses east and approaches the interface of the Styx Coal Measures and Back Creek Group (e.g. refer **Figure 8-3[b]**), the differential in hydraulic parameters act as boundary effects which results in predicted drawdown then extending to the north (west of the fault) and toward the historic mine workings at Bowman.

Uncertainty Analysis including parameter sensitivity analysis (**Section 8.11 and Attachment 11**) suggest that drawdown could elongate further along the strike of the coal outcrop, however this is localised and not expected to encroach to any appreciable extent to the downstream reach of Tooloombah Creek (at the Deep Creek confluence) nor Styx River. Further analysis of the boundary effects of the fault and other parameters is discussed in **Sections 8.11.2 and 8.11.3**.

8.5.3 Quaternary Alluvium

As confirmed by the results of the TEM survey (**Attachment 5**), the more permeable 'Holocene' Quaternary alluvium is restricted to rare deep cut infills. The extent of predicted drawdown in the mapped Qa units are shown on **Figure 8-3[c]**. For the purposes of assessment, and connectivity with surface water (i.e. including identification of potential recharge and discharge areas), and considering watercourse bed gradients, the groundwater head plots are shown with the drawdown contours to demonstrate the magnitude of predicted changes due to groundwater drawdown in the Quaternary alluvium.

Some temporal drawdown is predicted in the Cenozoic sediments in the near vicinity of the open cut mining operation, where the saturated water table is present (albeit gradual and localised), and is predicted to gradually recover post-mining (**Section 8.9**). How these predicted changes would indirectly present and occur over the life of the CQC Project, and post-mining, are discussed separately in **Section 8.6**.

8.5.4 Back Creek Group

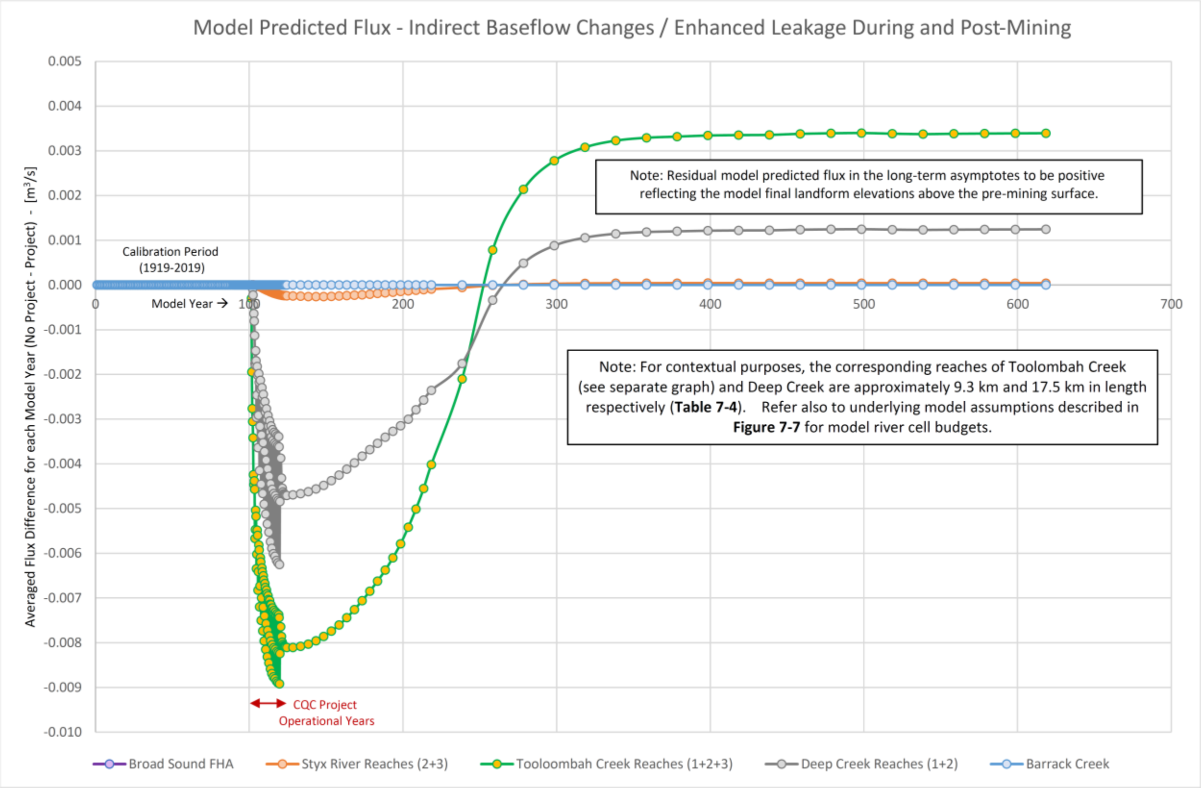
The Back Creek Group is the basal aquifer unit to the Styx Coal Measures and is presented to show the maximum groundwater level drawdown at depth (**Figure 8-3[d]**). Importantly, as described in **Section 4.2.1**, the depth to the top of the Back Creek Group varies significantly across the Styx River catchment (**Table 3-8**).

Relevantly, to the west of ML 80187, the Back Creek Group subcrops near the surface (**Figures 4-3[a] and 4-3[c]**) and therefore must be contextualised when reviewing the head plots presented in **Figure 8-3[d]**. Notably, head gradients are maintained to the west of the open cut mining operations in the reach of Tooloombah Creek downstream of the Mamelon Creek confluence, and is greater than the predicted head plots in the overlying Cenozoic Deposits, when referring to the 20 mAHD head contour (**Figures 8-3b] and 8-3[d]**). The relevance of this existing head gradient is then evident when considering model baseline baseflow / leakage estimates (**Table 7-17**) and corresponding potential impacts along Tooloombah Creek in **Section 8.6.2**.

8.6 PREDICTIVE MODEL – BASEFLOW IMPACTS / ENHANCED LEAKAGE

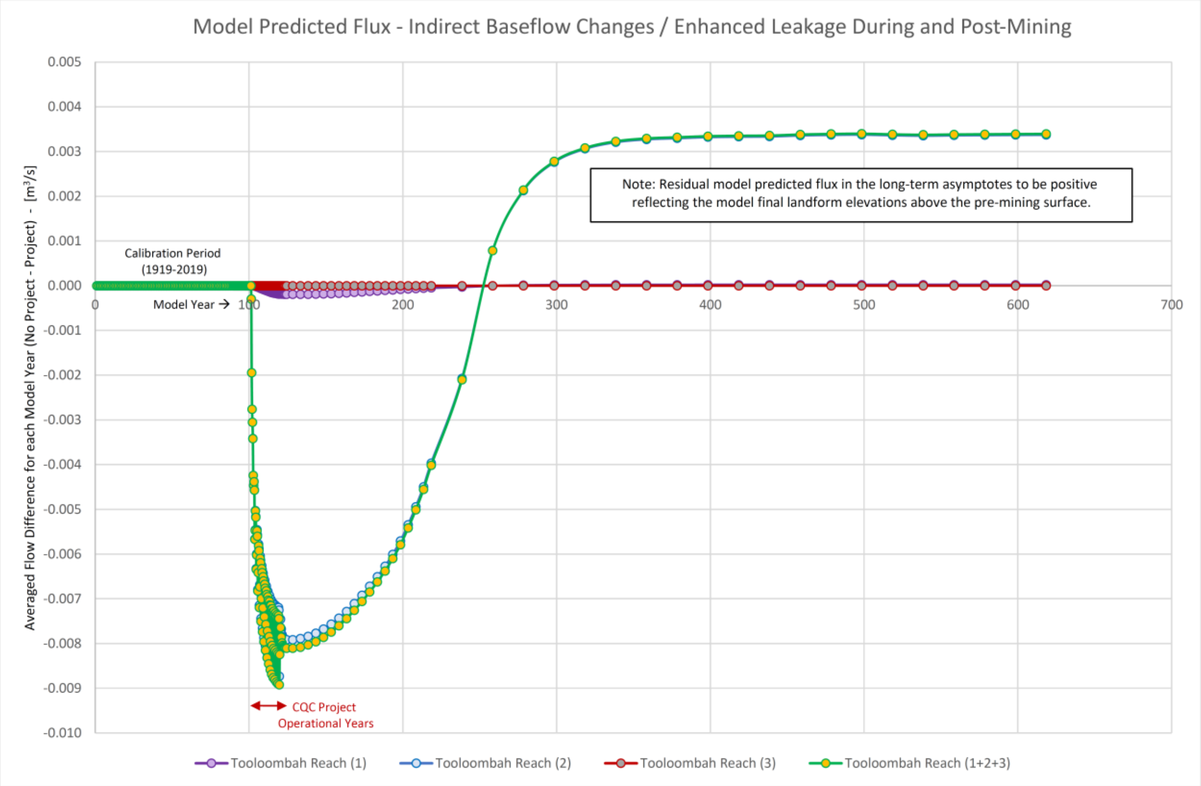
Model predicted baseflow changes and/or enhanced leakage as a result of the CQC Project have been determined by calculating the averaged differences in flux in model cells along specified watercourse reaches as presented in **Table 7-5** for each model year/period (i.e. a total of 618 years) and is presented in **Graph 8-3**. It is noted that fluctuations during the 18 year CQC Project operational years are considered an artefact of the model time steps / discretisation.

For the purposes of analysis, the model predicted flux along the three Tooloombah Creek reaches are also presented in **Graph 8-4** demonstrating that the changes primarily relate (as expected) to model reach (2) in the vicinity of the CQC Project, and to a far lesser extent both upstream of the Mamelon Creek Confluence and downstream of the Deep Creek confluence. Similarly, the averaged differences in flux along Deep Creek presented relate to the reach downstream of the Brussels Creek confluence, in the vicinity of the CQC Project. Relevantly, **Graph 8-3** also demonstrates the predicted changes in Barrack Creek are of little to no consequence (during mining and post-mining) and therefore further partitioning of Deep Creek would be superfluous.



Graph 8-3

Model Predicted Flux – Indirect Baseflow Changes / Enhanced Leakage During and Post-Mining



Graph 8-4

Model Predicted Flux – Tooloombah Creek Reaches Comparison

As shown on **Figure 7-4**, it is important to note the underlying model assumptions for the reaches when contextualising the predicted baseflow changes and/or enhanced leakage. When compared to the corresponding flow duration curves for Tooloombah Creek and Deep Creek, the quantum of maximum predicted volume changes (< 0.009 m^3/s for Tooloombah Creek and approximately 0.005-0.006 m^3/s for Deep Creek) averaged for a model year/period is by comparison at the lowest end of the reported flow scale (**Graphs 3-7 and 3-9**).

A brief summation is provided below for the Styx River, Tooloombah Creek, Deep Creek and other watercourses/drainage lines. Further analysis of the impacts of the predicted changes when considering other hydrological changes resulting from the excision of catchment for the CQC Project is presented in WRM Water & Environment (2020) and consequential effects in Eco Logical Australia Pty Ltd (2020a; 2020d).

8.6.1 Styx River

As shown on **Graph 8-3**, the model predicted changes to the Styx River reaches (2 and 3) downstream of the CQC Project, and upstream of the Broad Sound Declared Fish Habitat Area (Plan FHA-047), including the section traversing the historic mine workings at Styx No.3 State Coal Mine, are less than 0.0003 m^3/s for the combined 6.1 km length.

When considering the downstream Styx River reaches are subject to tidal influences as well as rainfall runoff from other contributing catchments, including Granite Creek and Montrose Creek, such model predicted volumetric differentials are considered negligible and would be indiscernible. Further discussion in relation to the lowest reach near the Broad Sound Declared Fish Habitat Area (Plan FHA-047) is provided in **Section 8.7.3**.

8.6.2 Tooloombah Creek

As described in **Section 7.5.3 (Table 7-5)** Tooloombah Creek was partitioned in the model for the three defined watercourse reaches, and for the purposes of assessment the results are presented separately and in combination on **Graph 8-4**.

As demonstrated, the corresponding changes in baseflow and/or enhanced leakage relates (as expected) primarily to the reach between Mamelon Creek confluence and Deep Creek confluence nearest to the CQC Project. That is, the quantum of maximum predicted volumetric differential (< 0.009 m^3/s for Tooloombah Creek) relates to the 9.3 km length of the defined watercourse, of which a proportion is subject to the onset of gradual indirect effects of predicted drawdown.

However, as shown on **Figure 7-4**, it is important to note the underlying model assumptions for the reaches when contextualising the predicted changes, and that if drawdown occurs within losing zones beneath the unsaturated zones of the watercourse which may develop from time to time (e.g. during extended dry periods) the additional model predicted flux (i.e. leakage) from the watercourse would not eventuate at that point in time. This is consistent with the conceptualisation presented in **Section 6.3.3** (**Figure 6-4**).

As shown on **Graph 8-4**, the model predicted changes to the Tooloombah Creek reach (1) downstream of Deep Creek confluence including the section downstream of the historic mine workings at Bowman are less than 0.0002 m^3/s for the 1.7 km length. When considering the downstream Tooloombah Creek reach is subject to tidal influences (i.e. within the identified tidal transition zone) as well as rainfall runoff from contributing catchments, including Tooloombah Creek and Deep Creek, such model predicted volumetric differentials would be indiscernible.

Further detailed analysis, considering other hydrological changes resulting from the excision of catchment for the CQC Project (primarily within the Deep Creek catchment) and consequential changes in flow/pools in Tooloombah Creek downstream of the Deep Creek confluence is presented in WRM Water & Environment (2020) and consequential effects in Eco Logical Australia Pty Ltd (2020).

8.6.3 Deep Creek

As described in **Section 7.5.3**, Deep Creek was partitioned in the model for the defined watercourse reach downstream of the Brussels Creek confluence and the results presented in **Graph 8-3**. The corresponding changes in baseflow and/or enhanced leakage relates (as expected) primarily to the reach downstream of the Brussels Creek confluence nearest to the CQC Project. That is, the quantum of maximum predicted volumetric differential (approximately 0.005-0.006 m^3/s for Deep Creek) relates to the 17.5 km length of the defined watercourse, of which a proportion is subject to the onset of gradual indirect effects of predicted drawdown.

However, as shown on **Figure 7-4**, it is important to note the underlying model assumptions for the reaches when contextualising the predicted changes, and that if drawdown occurs within losing zones beneath the unsaturated zones of the watercourse which may develop from time to time (e.g. during extended dry periods) the additional model predicted flux (i.e. leakage) from the watercourse would not eventuate at that point in time. This is consistent with the conceptualisation presented in **Section 6.3.3** (**Figure 6-4**).

Further detailed analysis, considering other hydrological changes resulting from the excision of catchment for the CQC Project within the Deep Creek catchment and consequential changes in flow/pools in Deep Creek is presented in WRM Water & Environment (2020) and consequential effects in Eco Logical Australia Pty Ltd (2020a).

8.6.4 Other Drainage Features

As the invert of other drainage features across ML 80187 are generally not as incised and deep-cut as the watercourses of Tooloombah Creek and Deep Creek, groundwater levels in lower lying topographic areas and drainages are typically greater than 8-10 m, and therefore model predicted changes in baseflow and/or enhanced leakage in the local surface water drainages across the tenement are considered to be negligible.

8.7 PREDICTIVE MODEL – GROUNDWATER DRAWDOWN PREDICTIONS AT FEATURES

8.7.1 Private Landholder Bores

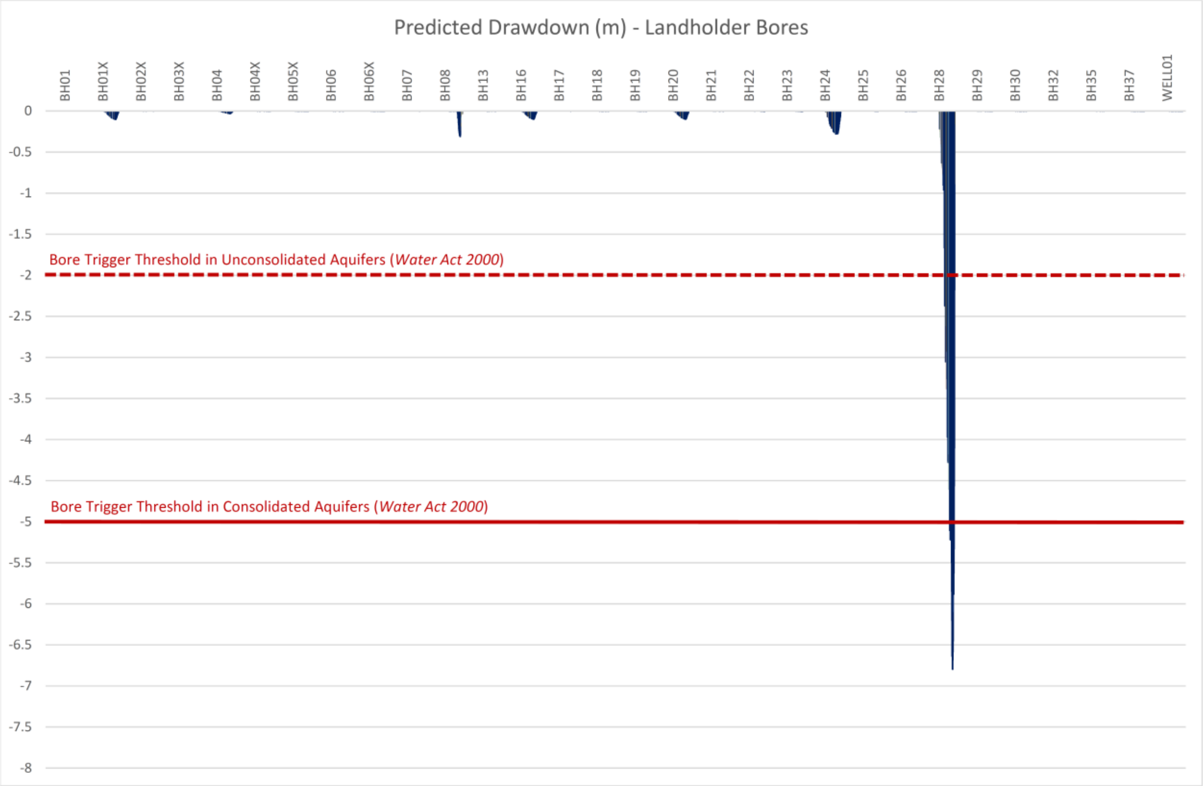
The maximum predicted groundwater drawdown on private landholder bores identified in the vicinity of the CQC Project are tabulated in **Table 8-4**.

Table 8-4
Maximum Predicted^ Groundwater Drawdown at Private Landholder Bores

Bore	Hydrogeological Unit	Model Predicted Maximum Drawdown	Relative Location	Other Details
BH28 [McCartney (97864)]	Back Creek Group [Consolidated Aquifer]	6.8 m (>5.0 m)	South-west of ML 80187	SWL (1998) = 12 mbgl Screen Interval = 32-54 mbgl
BH08 [McCartney (91715)]	Styx Coal Measures [Underburden] [Consolidated Aquifer]	0.3 m (<0.5 m)	South-west of ML 80187	SWL (1994) = 25 mbgl Screen Interval = 29-38 mbgl
BH24 [Well No.1 (84983)]	Quaternary Alluvium [Unconsolidated Aquifer]	0.3 m (<0.5 m)	North of ML 80187	SWL (1960) = 1.74 mbgl Screen Interval = 2-2.6 mbgl
BH20 [Monopoly (57794)] (including adjacent bores BH16/BH01X)	Quaternary Alluvium [Unconsolidated Aquifer]	0.1 m (<0.5 m)	North of ML 80187	SWL (BH16/BH01X) = 5.3-6.8 mbgl Screen Interval = 6-9 mbgl
All Other Identified Landholder Bores and Database Search Records	Varies	0.0 m (<0.5 m)	Within and Beyond 10 km of the CQC Project	Refer **Section 5.2.3** and **Attachment 4 (Table A4-2)**

^ Refer to **Sections 8.11 and 8.12** for predictive model uncertainty analysis, limitations and uncertainty minimisation opportunities.

Only one private landholder bore (BH28 [McCartney {97864}]) is predicted to be impacted beyond the 5 m bore trigger threshold defined in the *Water Act 2000* for consolidated aquifers. All other private landholder bores (BH Series) are predicted to be below <0.5 m and would not exceed the 2 m bore trigger threshold defined in the *Water Act 2000* for unconsolidated aquifers (**Graph 8-5**).



Graph 8-5
Model Predicted Groundwater Drawdown – Private Landholder Bores

8.7.2 Springs, Wetlands and Groundwater Dependent Ecosystems

No groundwater springs were identified at the CQC Project by CDM Smith (2018e), therefore no groundwater drawdown predictions/impacts are presented.

The inferred depth to groundwater table is presented in **Figure 5-4**, and consistent with the groundwater monitoring datasets (**Section 5**) and previous findings is generally at approximately 10 m and greater within ML 80187.   With the exception of the deep-cut and incised watercourses, groundwater levels in lower lying topographic areas and drainages are also typically greater than 8 m. As demonstrated by the various investigations (**Sections 3.5, 5.1.4 and 5.3.2**), wetlands in the vicinity of the CQC Project are unlikely to be dependent on or connected to the regional groundwater table (measured at 10 mbgl and greater [**Table 5-6**]). The wetland systems are considered to exist due to the presence of clays in the shallow subsurface of the Cenozoic sediments and localised topographic undulations, which allow perched water tables / moisture profiles to develop and persist after rainfall events (**Plate 3-18 and Figures 6-5[a&b]**).

The maximum predicted groundwater drawdown at existing groundwater monitoring bores at Wetland 1 (WMP25), Wetland 2 (WMP14 and WMP27) and the Alluvial Vine Thicket Assessment Area (WMP24 and WMP28) are summarised in **Table 8-5**.

Table 8-5
Maximum Predicted^ Groundwater Drawdown at Wetlands and Other Features

Feature	Recorded Depth to Groundwater Table [**Table 5-6**]	Evidence of Regional Groundwater Table Use	Maximum Model Predicted Drawdown at Existing Monitoring Bores
Wetland 1 (Figure 6-5[a])	>10 m (WMP25)	Unlikely#	2.7 m (WMP25)
Wetland 2 (Figure 6-5[a])	20 m (WMP14 and WMP27)	No*	1.3 m (WMP14) 1.9 m (WMP27)
Alluvial Vine Thicket Assessment Area	>10 m (WMP28)	No*	4.6 m (WMP28)

^ Refer to **Sections 8.11 and 8.12** for predictive model uncertainty analysis, limitations and uncertainty minimisation opportunities.

* CDM Smith (2018g).

\# The shallow bore holes (BH1 to BH3) installed in Wetland 1 (**Section 5.1.4**) recorded unsaturated profiles to approximately 8 mbgl with increasing moisture profiles from approximately 8 mbgl, in line with actual evapotranspiration extinction depths (**Section 7.5.5**).

The maximum groundwater drawdown influence / depressurisation as presented in **Section 8.5 and Attachments 14 and 15** have been used independently by Orange Environmental Pty Ltd (2020) and Eco Logical Australia Pty Ltd (2020a) for the purposes of assessment of impacts to potential groundwater dependent ecosystems (including consideration of relevant dependence and impact thresholds).

Importantly, the potential impacts of the CQC Project on surface water resources (which may or may not be groundwater dependent) are assessed separately by Orange Environmental Pty Ltd (2020) and WRM Water & Environment (2020). Similarly, the potential impacts on groundwater dependent ecosystems (including combined hydrogeological and hydrological changes i.e. catchment excision) are assessed separately by Orange Environmental Pty Ltd (2020) and Eco Logical Australia Pty Ltd (2020a). Nevertheless, relevant comparisons have been provided (including preliminary flow duration curves in **Sections 3.3.3 and 3.3.4**) for the purposes of assessment context.

8.7.3 Broad Sound Declared Fish Habitat Areas

For the purposes of relative comparison, private landholder bores within the numerical groundwater model extent between the CQC Project and Broad Sound Declared Fish Habitat Area (Plan FHA-047) were investigated to numerically predict groundwater drawdown (where it asymptotes) in order of millimetres.

Thus, the results (<0.001 m) at Well01, BH36 and BH37 supports the conclusion that there would be no decline in groundwater levels predicted at the nearest point of the Broad Sound Declared Fish Habitat Area (Plan FHA-047), which in any case, fluctuate naturally due to surface water (tide) levels and catchment flows in the Styx Surface Water Basin. An example of the distances the low tide extends in the Styx River (i.e. to Rosewood Island) and Broad Sound Declared Fish Habitat Area (Plan FHA-047) is evident in available aerial photography (**Figure 8-4**).

8.7.4 Recorded Groundwater Fauna Locations / Stygofauna Habitat

As presented in **Table 5-9**, with the exception of Exploration Hole STX093 (near Deep Creek), all other stygofauna sampling locations recorded no groundwater fauna. This is not unexpected given the typically saline nature of the groundwaters (**Section 5.5**) and the targeted groundwater investigations (**Attachments 5 and 7**) which confirm that the groundwater systems are not significant aquifers at the CQC Project.

It is noted that the recorded EC at STX093 was 11,881-17,579 µS/cm. However, when considering the environmental values and WQOs in **Section 6.2**, and the results of the TEM survey, the groundwater associated with the Qa units (AZ6) are of generally better (surface recharge/connectivity) water quality when compared to the Quaternary Pleistocene alluvium [Qpa] unit (CZ2), and therefore of relative greater environmental value.

As described in **Section 5.3.4**, all the 'Riverside' sampling locations which recorded stygofauna were located toward the Styx River mouth, downstream of the CQC Project.

The maximum predicted groundwater drawdown at STX093 and BH36, BH37 and Well01 are summarised in **Table 8-6**. The maximum predicted drawdown influence is presented separately in **Section 8.5**, including Qa and Qpa units.

Table 8-6
Maximum Predicted^ Groundwater Drawdown at Bores with Recorded Groundwater Fauna

Sampling Location	Total Bore Depth	Depth to Groundwater Table	Predicted Maximum Drawdown at Sampling Location
STX093	75 m	12 m	53.9 m
Riverside Well [Well01]	7.6 m	6.2 m	<0.001 m (Nil) ⁺
Riverside 1 [BH37]	7 m	6.8 m [Dry]	<0.001 m (Nil) ⁺
Riverside 3 [BH36]	11 m	5.65 m	<0.001 m (Nil) ⁺

^ Refer to **Sections 8.11 and 8.12** for predictive model uncertainty analysis, limitations and uncertainty minimisation opportunities.
* CDM Smith (2018g).
⁺ Refer to **Section 8.7.3**.

Within the open cut extent, and spatial extent of model drawdown predictions, any stygofauna present would be locally impacted by groundwater drawdown. The more permeable 'Holocene' Quaternary alluvium is restricted to rare deep cut infills, so despite the relative greater environmental value, based on the drawdown extents predicted in **Section 8.5.3**, the localised impacts to stygofauna would be limited. Refined impact assessment has been undertaken separately by Eco Logical Australia Pty Ltd (2020a).

8.7.5 Riparian Vegetation

The potential impacts of the CQC Project on riparian vegetation, including consequential effects resulting from groundwater drawdown and baseflow impacts / enhanced leakage (presented in **Sections 8.5 and 8.6**) are described separately in Eco Logical Australia Pty Ltd (2020a).

8.8 PREDICTIVE MODEL – WATER BALANCE AND MODEL PERFORMANCE

8.8.1 Mass Balance Closure Error

The mass balance closure error statistics for the transient prediction and recovery model runs are presented in **Table 8-7** and achieves the generally accepted target threshold of <0.5% mass balance closure error (**Attachment 10**) **(Table A10-4)** in all cases.

Table 8-7
Transient Prediction and Recovery Model Mass Balance Closure Error Statistics

Model	Maximum Single Time Step Discrepancy	Final Cumulative Discrepancy	Maximum Cumulative Discrepancy
Transient Prediction	0.01%	0.01%	0.01%
Transient Recovery	0.38%	0.13%	0.14%

8.9 PREDICTIVE (RECOVERY) MODEL – POST MINE CLOSURE EQUILIBRIUM GROUNDWATER LEVELS

Predictive (recovery) modelling was completed with the application of processes as described in **Section 8.3.6**. At the completion of open cut mining operations (i.e. beginning of the predictive (recovery) model variant), all drain cells were deactivated. For the purposes of modelling and assessment, it is assumed that at the end of the open cut mining operations, no accumulated mine waters are stored or held in the voids prior to backfill but if so would only have the effect of reducing the recovery periods assuming the water is allowed to infiltrate and recharge the backfill spoil at depth.

As outlined in **Tables 7-9 and 7-10**, the predictive (recovery) modelling immediately follows the transient prediction stress periods and allows for the continued recovery of both historic workings and the CQC Project. Four (4) temporally varying periods have been considered in the model including backfill and mine closure (approximately 5 years post-mining) followed by longer term recovery periods (up to 500 years post-mining) for which the results are summarised and presented on **Figures 8-5[a-c]** and **Attachment 15**.

Figure 8-5[a] presents the post-mining recovery results in the Cenozoic deposits/regolith (Layers 2 and 3) and as shown in the long-term would substantially recover heads and re-establish gradient generally equivalent to the pre-mining heads and gradients (**Attachment 13**). Some localised mounding is predicted to occur where the final landform surfaces are elevated above the existing surface, and the resulting net gain effects evident in the predicted changes in baseflows and/or lesser leakage in Tooloombah Creek and Deep Creek after approximately 150 years (**Graph 8-3**).

Figures 8-5[b&c] similarly presents the post-mining recovery results in the Styx Coal Measures (Layers 5, 8 and 11) and Back Creek Group (Layer 12) and show groundwater heads in the long-term would substantially recover and re-establish gradients generally equivalent to the pre-mining heads and gradients (**Attachment 13**).

In addition to the post-mine closure equilibrium groundwater levels, comparisons of head gradients in the Cenozoic deposits/regolith (Layer 2) and Layer 8 (Styx Coal Measures) are presented on **Figures 8-6[a-f]** for:

- Stress Period 300 (+5 years post-mining);
- Stress Period 319 (+100 years post-mining); and
- Stress Period 320 (+500 years post-mining).

The head gradients show the regional groundwater flow directions toward the coast are maintained, and that the changes to the head gradients by the CQC Project are localised and temporal.

8.10 PREDICTIVE MODEL – CUMULATIVE IMPACTS

Anthropogenic land use within ML 80187 and surrounds is outlined in **Section 3.4.5**, including historic mine workings. As outlined in **Table 7-8**, cumulative impact predictions have been considered during the model variants to allow effects of ongoing recovery of historic mine workings at Ogmore and Bowman (**Sections 3.4.5 and 7.5.6**) to be modelled with future predictions. As discussed further in **Section 8.11.4,** existing landholder bore users were not explicitly modelled (i.e. no drain cells at landholder bores) and thus recorded levels are considered to incorporate the anthropogenic use.

The modelled effects of the historic mine workings are evident in the pre-calibration run results on **Figure 7-8[b]** (at the end of 1964) and **Graph 7-3**. Whilst available datasets and records suggest substantial recovery of groundwater pressures and levels at the historic mine workings at Ogmore and Bowman has already occurred, it is expected they will continue to gradually recover over the coming decades as well.

Cumulatively, the predicted groundwater drawdown effects as a result of the CQC Project (**Attachment 14**) do not extend as far as the historic Ogmore mine workings (some 8 km to the north and downstream beneath the Styx River) to result in any superposition effects and therefore is not expected to result in any discernible change to the location of the freshwater-saltwater interface (**Section 6.3.2**). That is, even if the interface was to be transient (or static) north of the historic Ogmore workings, there would not be expected to be any discernible change due to the CQC Project alone.

The cumulative effects of the historic mine workings at Bowman (beyond those predicted for the CQC Project alone) are predicted to be negligible given the limited extent and proximity of the historic workings in the north, and continued recovery since the cessation of mining. Nevertheless, as outlined in **Section 10.1.7**, consideration should be given to installing an additional groundwater monitoring bore (deep standpipe) to the north / north-east of Open Cut 2, within the first three (3) years of the operation for early detection of the propagation of depressurisation effects in the deeper coal seams toward the north-east of the open cut mining operation (and south of the historic mine workings).

In conclusion, the predictive cumulative modelling results demonstrate there is unlikely to be any superposition effects, thus, the predicted cumulative drawdown impacts at private landholder bores, springs, wetlands, groundwater dependent ecosystems, Broad Sound Declared Fish Habitat Area and on recorded groundwater fauna locations / stygofauna habitat and riparian vegetation are equivalent to the CQC Project alone. Further, it is demonstrated in **Section 8.6** that the model predicted baseflow changes and/or enhanced leakage from the Styx River downstream is considered negligible and would be indiscernible.

The potential cumulative impacts on surface water resources are assessed separately by Orange Environmental Pty Ltd (2020) and WRM Water & Environment (2020). Similarly, the potential cumulative impacts on groundwater dependent ecosystems (including combined hydrogeological and hydrological changes i.e. catchment excision) are assessed separately by Orange Environmental Pty Ltd (2020) and Eco Logical Australia Pty Ltd (2020a).

8.11 PREDICTIVE MODEL – UNCERTAINTY ANALYSIS (INCLUDING PARAMETER IDENTIFIABILITY)

As discussed in **Section 7.1.3**, a range of scenario-based analyses and statistical methods were initially proposed for consideration as part of the uncertainty analysis, and during the course of ongoing review and implementation the improvements to the numerical groundwater model (and peer review), were finalised as outlined below in **Sections 8.11.1 to 8.11.5**. Roman numerals have been used for ease of reference to each individual consideration in **Section 7.1.3** and the relevant analysis or statistical methodology applied.

A combination of parameter identifiability, sensitivity and qualitative analyses have been used to identify bounds (or constraints) by available observations and then investigate if and/or how such parameters affect the model predictions. This recognises the challenge of non-uniqueness, and the possibility that multiple combinations of parameters may be equally good at fitting historical measurements, but has been used in support of the combination of parameters applied in the CQC-LF3 Groundwater Model.

Notably, in response to the recommendations made in the penultimate stage of peer review (**Table A2-6**), an additional three (3) numerical model sensitivity runs [X, XI, XII] (**Section 8.11.6**) were completed to build further confidence in the numerical groundwater model predictions and support the improved model classification. In conjunction, with additional post model construct and post-calibration validation exercises using datasets made available by CQCPL during subsequent investigations in 2020 (**Sections 7.8.1 to 7.8.3**), and as summarised in **Flowchart A2-1 (Attachment 2)**, robust uncertainty analysis has been completed in an "*open, honest and transparent way*" as required by the IESC's *Information Guidelines Explanatory Note: Uncertainty Analysis – Guidance for Groundwater Modelling within a Risk Management Framework* (dated 17 December 2018).

8.11.1 Parameter Identifiability

The identifiability of a parameter is mathematically defined in Doherty (2015) and Doherty and Hunt (2009) as[31]:

> *… the square of the cosine of the angle between a parameter and its projection onto the calibration solution space. It is also the magnitude of the diagonal element of the resolution matrix corresponding to that parameter.*

In more general terms, when the identifiability of a parameter is:

- **equal to 0.0** – the calibration dataset (at the time) is completely uninformative of a parameter (i.e. insensitive).
- **between 0.0 and 1.0** – the calibration dataset (at the time) is informative of more than one parameter (i.e. is shared) and the parameter cannot be resolved uniquely (i.e. non-uniqueness).
- **equal to 1.0** – the parameter is completely informed (estimated) by the calibration dataset (at the time), and that measurement noise is then directly responsible for any estimate error.

For the purposes of this uncertainty analysis, the identifiability for all hydraulic parameters used in the transient calibration model (more than 7,000) was calculated and is presented spatially for each model layer in **Attachment 16**. These spatial plots help to support and inform the analyses outlined in the following sub-sections and can be used to target ongoing monitoring programs for future model validation as more data is collected over time. It is relevant to note that for presentation purposes only, an arbitrary cut-off for parameter identifiability of <0.1 has been used and those parameters (more than 96% of the dataset) are shown as a faint "+".

The spatial plots with the cut-off applied help to demonstrate where calibration datasets spatially exist and identify those that are of less relevance (i.e. distant) to the CQC Project, but nevertheless within the model domain. For example, the cluster of available groundwater datasets from government database searches (**Section 5.2.2**) in the far north-east and far south-west of the model domain are evident (Layers 2 and 13, respectively in **Attachment 16**).

In summary, the spatial plots show that based on the calibration datasets in the vicinity of the CQC Project, the parameters for each layer of interest are as follows:

- Layer 2 – $K_{HORIZONTAL}$/%Infiltration and $K_{HORIZONTAL}$;
- Layer 3 – $K_{HORIZONTAL}$ and S_y;
- Layer 4 – $K_{HORIZONTAL}$;
- Layer 5 – $K_{HORIZONTAL}$ and $K_{HORIZONTAL}/K_{VERTICAL}$;
- Layer 7 – $K_{HORIZONTAL}$ and $K_{HORIZONTAL}/K_{VERTICAL}$;
- Layer 9 – $K_{HORIZONTAL}$ and $K_{HORIZONTAL}/K_{VERTICAL}$;
- Layer 11 – $K_{HORIZONTAL}$, $K_{HORIZONTAL}/K_{VERTICAL}$ and S_y;
- Layer 12 – $K_{HORIZONTAL}/K_{VERTICAL}$ and $K_{HORIZONTAL}$; and
- Layer 13 – $K_{HORIZONTAL}$ and $K_{HORIZONTAL}/K_{VERTICAL}$.

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[31] From Section 8.7 IDENTPAR, Pages 82-83 in *PEST Statistical Postprocessing*.

It is noted that the identifiability of parameters in Layers 6, 8 and 10 (i.e. aggregated coal seams and relatively thin model layers) and Layer 14 (basement) were generally all less than <0.1.

The parameter identifiability in Layer 13 only related to pilot points distant to the CQC Project (far south-west) and are therefore not considered further. Similarly, relevant parameters identified in Layer 12 (i.e. $K_{HORIZONTAL}/K_{VERTICAL}$) are mostly at distance to the east and south whereby model resolution (and assessment focus) is lower.

The results of the parameter identifiability analysis for the hydraulic parameters are supportive of the targeted design for site-specific investigations (**Section 5.6**) including localised aquifer testing, open end and packer testing (**Attachment 7**) as well as the TEM survey (**Attachment 5**) for the upper model layers (Layers 2-4), and laboratory core permeability and porosity testwork (**Attachment 9**) for the model middle layers (Layers 5-11).

For the model bottom layers (Layer 12+) (**Section 7.4.1**), it is noted that during the site-specific investigations by GES (2020) (**Attachment 9**), drill core was unable to be sourced for the Back Creek Group (Permian Measures) from historic exploration core trays nor more recent drill campaigns (i.e. WMP31). As described in **Section 4.2.1**, a second drill hole (WMP32) was also proposed, but was subsequently installed adjacent WMP31 (WMP32^{A}) and is discussed in **Section 10.1.9** for future model validation.

Each of the parameters identified including $K_{HORIZONTAL}$/%Infiltration, $K_{HORIZONTAL}$, $K_{HORIZONTAL}/K_{VERTICAL}$, S_s and S_y have been specifically investigated across all layers as part of the quantitative Uncertainty Analysis (**Attachment 11**) and is discussed further in **Section 8.11.2**.

During the penultimate stage of the peer review, it was recommended that river bed conductance also be investigated and has been considered separately in **Section 8.11.6**. It should however be recognised that the river bed conductance is: (a) only applicable along RIV cells within the model domain; and (b) is a function of several variable dimensions which are estimated for the modelled reach of the watercourses.

8.11.2 Quantitative Uncertainty Analysis

(IV) Hydraulic Conductivity Zones (Pilot Points) – Alluvium / Styx Interburden / Coal Seams / Basement Aquifer (Vertical & Horizontal) [Upper – Middle – Bottom Layers]

Ranges and distributions applied to hydraulic properties (and surrogate recharge) in the improved numerical groundwater model as part of the quantitative uncertainty analysis (**Attachment 11**) are summarised below:

- lognormal distribution with 0.5 standard deviation for $K_{HORIZONTAL}$, S_s and $K_{HORIZONTAL}$/Infiltration% ratio;
- truncated lognormal distribution with 0.5 standard deviation for $K_{HORIZONTAL}/K_{VERTICAL}$ and a minimum of 1 (i.e. to maintain anisotropy greater than 1); and
- lognormal distribution with 0.25 standard deviation for S_y.

Latin Hypercube Sampling (LHS) is a statistical method which has been used (*in lieu* of the Monte Carlo Sampling which was undertaken for the previous numerical groundwater model [**Section 7.1.1**]) to generate a near-random sample of parameter values from the above multi-dimensional distribution. Other benefits of using LHS (e.g. simplicity and speed) are outlined in **Attachment 11**.

A total of 1,000 model runs were completed with a calibration cut-off of 3% SRMS (i.e. 50% greater than the original transient calibration model). The UA output datasets have been presented in the form of percentiles, consistent with the IESC's *Information Guidelines Explanatory Note: Uncertainty Analysis – Guidance for Groundwater Modelling within a Risk Management Framework* (dated 17 December 2018).

Key aggregate metrics are presented in **Table 8-8** to provide an indication of the magnitude of differences for the peak mine inflows and changes in baseflow / enhanced leakage estimates, and corresponding probabilities (i.e. very likely to exceed UA 10%ile to very unlikely to exceed UA 90%ile).

In summary, the Uncertainty Analysis (**Attachment 11**) results indicate the improved numerical model predictions are on the lower side of the UA 50%ile (i.e. as likely as not to exceed), but it is noted that the SRMS error diverges as the UA %ile increases (which is not unexpected).

Table 8-8
Uncertainty Analysis Summary for Key Aggregate Metrics

Key Aggregate Metric		UA 10%ile		UA 33%ile	UA 50%ile	UA 67%ile		UA 90%ile
		Very Likely to Exceed	⟵		⟷		⟶	Very Unlikely to Exceed
Peak Mine Inflow (ML/year)	OC1	121.7	**123**	189.4	223.2	278.4		401.5
	OC2	357.7	**414**	514.3	631.9	784.2		1,152.3
	Combined	404.4	**440**	579.0	696.5	848.3		1,241.1
Peak Baseflow / Leakage Change (m^3/s)	Tooloombah Creek	0.008	**0.009**	0.010	0.012	0.013		0.017
	Deep Creek	0.005	**0.006**	0.009	0.011	0.013		0.020
	Styx River	0.0001		0.0002	0.0002	0.0003	**0.0003**	0.0004
	Mamelon Creek	0.0000	**0.0000**	0.0000	0.000003	0.000013		0.000038
Storage Change for Broad Sound Fish Habitat Area (ML/year)		0.00	**0.00**	0.00	0.00	0.00		< 0.01
Calibration (SRMS Error)		2.59%	**2.01%**	2.73%	2.79%	2.86%		2.95%

Bold Underline value = Base case or "calibrated" model results as presented in **Section 7.7**.

Note: Each value in a given column is independent of the other values in that column (e.g. 404.4 ML/year peak mine inflow does not necessarily occur in the same run as 0.008 m^3/s peak baseflow / leakage change to Tooloombah Creek).

(VII) Specific Storage and Specific Yield Parameters

As described above in **(IV)** above, ranges and distributions applied for hydraulic properties in the improved numerical groundwater model as part of the quantitative Uncertainty Analysis (**Attachment 11**) included:

- lognormal distribution with 0.5 standard deviation for specific storage (S_s); and
- lognormal distribution with 0.25 standard deviation for specific yield (S_y).

The results of the analysis are summarised (collectively) in **Table 8-8** and further details are presented in **Attachment 11**, but it is noted that relative to other hydraulic parameters in the model layers, the applied S_s values appear to be generally of low identifiability (**Attachment 16**). Nevertheless, application of physical upper limit for unconsolidated materials was as determined by Rau *et al.* (2018) and for the purposes of the uncertainty analysis, the ranges / distributions were not constrained.

It is noted specific yields used in the numerical groundwater model are tabulated in **Section 7.7.3**. Effective porosity laboratory measurements were also taken on a representative sub-sample of the stratigraphic column (**Attachment 9**). Relevantly, the average effective porosity was 1.1% which is comparable to the maximum S_y values used in the numerical groundwater model.

8.11.3 Scenario-Based Sensitivity Analysis

(I) Tidal Boundary Condition Range (incorporating Sea Level Rise Predictions)

For the purposes of freshwater-seawater interface analysis, the predictive model was re-run for two (2) scenarios to present the maximum predicted groundwater drawdown differences in Layers 2 (Cenozoic deposits/regolith) and 8 (Styx Coal Measures) with the applied fixed head boundary condition at the Styx River mouth and along the mapped estuarine reach of the Styx River (i.e. to the railway crossing):

- reduced from 3.5 mAHD to 2 mAHD; and
- increased from 3.5 mAHD to 4.5 mAHD.

The bounds (2 mAHD and 4.5 mAHD) were determined based on the review of tidal datasets and analysis set-out in **Section 3.3**, as well as consideration of sea level rise projections (**Section 8.11.5**).

As shown on **Figures 8-7[a] and 8-7[b]**, the differences in maximum predicted groundwater drawdown in Layers 2 and 8 are negligible despite there being a 2.5 m differential in the fixed head boundary condition.

(II) Rainfall Recharge Totals (incorporating Climate Change Scenario Range and Adopted Alluvium / Regolith [%] Recharge)

For the purposes of climate change scenario analysis, the predictive model was re-run for two (2) scenarios to present the average groundwater take/inflow changes if rainfall recharge totals applied across the model domain is:

- reduced by 20%; and
- increased by 20%.

The bounds (-20% to +20%) were determined based on the climate change considerations outlined in detail in **Section 8.11.5**.

These broad bounds were considered appropriate when also noting the compounding maximum evapotranspiration rates and extinction depths applied as described in **(III) (Section 8.11.4)**, recognising rainfall recharge can have some (albeit variable) correlation.

As described above in **(IV) (Section 8.11.2)**, ranges and distributions applied for hydraulic properties in the improved numerical groundwater model as part of the quantitative Uncertainty Analysis also included lognormal distribution with 0.5 standard deviation for $K_{HORIZONTAL}$/Infiltration% ratio and is detailed in **Attachment 11**.

(V) Geological Structure (Fault) Zone of Hydraulic Conductivity [Enhanced or Reduced]

For the purposes of the geological structure (fault) zone analysis, the predictive model was re-run for one (1) enhanced scenario to present the maximum predicted groundwater drawdown differences in Layers 2 (Cenozoic deposits/regolith) and 8 (Styx Coal Measures) with a higher (factor x 10) $K_{VERTICAL}$.

As shown on **Figures 8-8[a], 8-8[b] and 8-8[c]**, the differences in maximum predicted groundwater drawdown in Layer 2 is very localised whilst Layer 8 is negligible.

Given the evidence of boundary effects already at the Styx Coal Measures and Permian Measures interface based on the CQC-LF3 case, and very localised changes based on the increased $K_{VERTICAL}$ factor (**Figure 8-8[b]**), a reduced vertical hydraulic conductivity (i.e. less permeable barrier) scenario was not considered any further.

8.11.4 Other Qualitative Analysis

(III) Maximum ET Rate and Extinction Depths

Detailed considerations were initially made for the application of representative evapotranspiration conditions as outlined in **Section 7.5.5** and identified during the peer reviews (**Attachment 2**). Specific evapotranspiration considerations for future climate change predictions are also discussed in **Section 8.11.5**.

A schematic showing the maximum rate (and extinction depths) of evaporation, and how applied across the model domain is shown on **Figures 7-6 and 7-7**, and the corresponding evapotranspiration flux presented on **Figure 7-11**.

On the basis that the depth to groundwater table in many areas in the vicinity of the CQC Project are beyond 10 m, it was considered that separate scenario model re-run (e.g. with lesser extinction depths or higher maximum ET rates) would therefore be of little to no consequence. However, it is noted that the climate change scenario ranges (**Section 8.11.5**) could in effect capture some corresponding sensitivities, recognising rainfall recharge can have some (albeit variable) correlation.

Nevertheless, during the penultimate stage of the peer review, it was recommended the separate scenario model be re-run and is presented in **Section 8.11.6**.

(VI) Depth Dependence (Depth Function) in Coal Seams

As described in **Section 6.3** (**Table 6-4**) and shown on **Graph 5-12**, a depth dependent $K_{HORIZONTAL}$ has been applied to the coal seams. Further to the results of the parameter identifiability analysis in Layers 6, 8 and 10 (i.e. aggregated coal seams and relatively thin model layers) which were generally all less than <0.1, it is known in Eastern Australian coal basins that seam permeability typically reduces with depth, and therefore additional scenarios (i.e. without depth dependence) were not considered necessary.

Whilst the calibration process did not enforce depth-dependence (except in initial values and min/max parameter value bounds) the quantitative UA (**Section 8.11.2**) did explore varied coal seam permeability values.

(VIII) Spoil Properties in Backfilled Voids

As described in **Section 8.3.3**, the backfilling process is simulated by applying TVM properties to reflect the changes in the host rock properties (pre-mining) to reflect the backfill spoil (broken, less consolidated rock) (**Table 8-2**).

In accordance with the previous peer review, by comparison to the previous numerical groundwater flow model (**Section 7.1.1**), higher permeability and storage properties have been applied as an improvement and therefore additional scenarios (i.e. without TVM properties) were not considered necessary to repeat. In addition to the TVM properties applied, a higher infiltration rate (enhanced rainfall recharge in spoil) was accommodated in the improved groundwater model by assigning a higher rainfall recharge percentage (i.e. 5% of rainfall).

(IX) Predictive Sensitivity for Increased Landholder Pumping

Landholder bore use is described in **Section 5.2.3**, specifically noting BH20, and adjacent BH16 and BH01X, recognising there does not appear to be any distinct response in groundwater levels at these bores. Existing landholder bore users were therefore not explicitly modelled (no drain cells at landholder bores) and thus recorded levels are considered to incorporate the anthropogenic use.

Based on the results of the numerical groundwater model outputs, review of the BH20-BH01X-BH16 monitoring, and consideration that use in the vicinity of the CQC Project is limited due to generally poor quality beyond the watercourses, a specific sensitivity scenario was not undertaken as it was unlikely to be of any consequence when considering all the other model parameterisation investigated.

8.11.5 Climate Variability / Climate Change Considerations

Climate Variability

Historic climate variability has been incorporated in the numerical groundwater model for the calibration period (**Section 7.5.4**; **Graph 3-2** and **Graph 7-3**) and is recognised in the annual and monthly rainfall totals.

As described in **Section 8.2.3**, climate is kept constant in the forward prediction model runs to allow the output analysis to isolate from modelled mining effects for impact assessment purposes. Episodic flood (recharge) events which are recognised in the historic climate variability are also not specifically applied in the forward prediction model and therefore allows for conservative assessment.

Nevertheless, climate change predictions are considered in the uncertainty analysis (as a sensitivity scenario) and is discussed below.

Climate Change Predictions, Uncertainty and Groundwater Modelling Application

In November 2019, an independent report completed by Alluvium Consulting (2019) for the Qld Government Queensland Water Modelling Network titled '*Critical Review of Climate Change and Water Modelling in Queensland'* was published. Besides policy-related matters and efficacy to mitigate and adapt, the report specifically raises questions of compounding uncertainty in relation to:

- magnitude of climate change (and uncertainty in which of the ranges of future scenarios is most likely);
- speed of climate change; and
- the impacts on specific areas and regions.

Each of the above (magnitude, timing and potential impacts) are considered and outlined below.

Future climate projections are available at the Commonwealth Government website (Climate Change in Australia – Projections for Australia's NRM Regions)[xix]. The future climate projections are based on the latest set of climate models, as used in the Intergovernmental Panel on Climate Change (IPCC)'s Fifth Assessment Report (referred as the CMIP5 set of models). The CMIP5 climate models consider a range of potential emission scenarios to allow comparison, of which most used the following three (as presented in the Special Report of Emissions Scenarios [SRES] [IPCC, 2000]):

- **B1 (Low Emission) Scenario** – Assuming a convergent world with low population growth, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.
- **A1B (Medium Emission) Scenario** – Assuming a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies, with a balanced emphasis on all energy sources. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income.

- **A2 (High Emission) Scenario** – Assumes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than other scenarios.

Representative Concentration Pathways (RCPs) are also used by the CMIP5 climate models (where data is available) and comparisons with the three scenarios from the SRES are shown on **Figure 8-9[a]**. In summary, RCP4.5 is effectively equivalent to the SRES B1 (Low Emission) Scenario and RCP8.5 is at an equivalent trajectory as SRES A2 (High Emission) Scenario, albeit at a lesser level.

The CQC Project is located within the East Coast Cluster (**Figure 8-9[b]**) (or more specifically the East Coast North Sub-cluster) with a predominantly sub-tropical climate with regional variations such as some tropical influences in the north. Within the East Coast North Sub-cluster, the following rainfall and temperature future climate projections are relevantly noted:

- Rainfall changes are possible, but unclear.
- Increased intensity of extreme rainfall events is projected, with high confidence.
- Average temperatures will continue to increase in all seasons (very high confidence).
- More hot days and warm spells are projected with very high confidence.

Despite the lack of clarity for potential rainfall changes for forward predictions, the effects of climate change on annual rainfall and evaporation in the Styx River catchment have been taken from the Climate Change in Australia (CCiA) Model East Coast Climate Futures Projections and are presented in **Tables 8-9 and 8-10**. For ease of comparison, the consensus of models for the three SRES scenarios for rainfall and evaporation in 2030 and 2090 are presented in **Table 8-9**. These results were selected to correspond with the median year of the CQC Project (i.e. 2030) and longer-term projections post-mining (i.e. 2090).

Table 8-9
East Coast Climate Futures Projections – Percentage Change in Rainfall and Evaporation [SRES]

Climate Futures Predicted Change		Annual Evaporation (Percentage Change)									
		Large Decrease (< -4.6%)		Small Decrease (-4.6% to -1%)		No Change (-1% to +1%)		Small Increase (+1% to +4.6%)		Large Increase (> +4.6%)	
Annual Rainfall (Percentage Change)	Much Wetter (> +15%)									□ ×	
								■ ×			■ ×
	Wetter (+5% to +15%)							■ ×	■ ×	□ ×	■ ×
										■ ×	■ ×
	Little Change (-5% to +5%)					□ ×	□ ×	■ ×	■ ×	■ ×	■ ×
		■ ×	■ ×			■ ×			■ ×	■ ×	■ ×
	Drier (-15% to -5%)						□ ×	□ ×			
					■ ×	■ ×				■ ×	■ ×
	Much Drier (< -15%)										

Source: After https://www.climatechangeinaustralia.gov.au/en

Cell Legend:

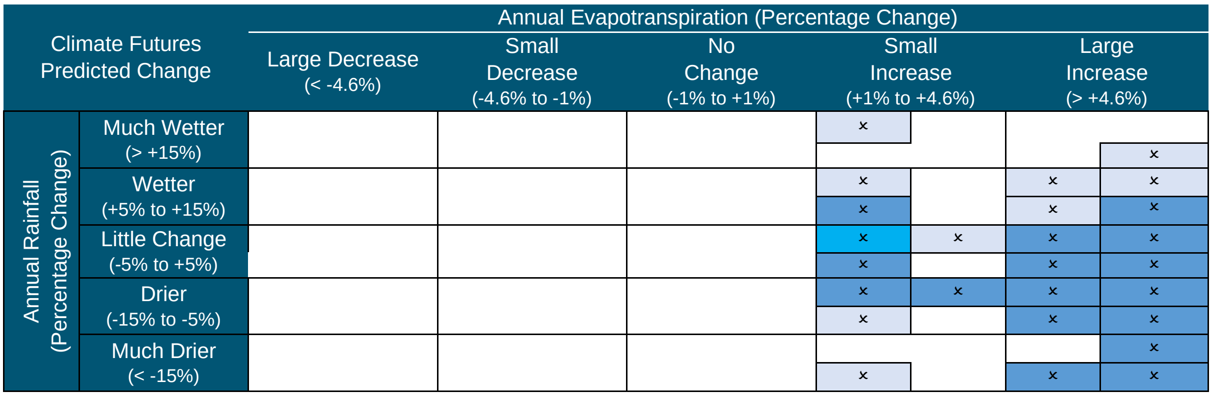
2030 – B1 **[10 Models]**	**2030 – A1B** **[11 Models]**
2030 – A2 **[9 Models]**	**2090 – A2** **[9 Models]**

□ **Very Low Consensus (<10% of Models)**

■ **Low Consensus (10-33% of Models)**

Equivalent data for the RCP scenarios (RCP4.5 and RCP8.5) for rainfall and evapotranspiration in 2040 (end of mining) and 2090 are presented in **Table 8-10**.

Table 8-10
East Coast Climate Futures Projections – Percentage Change in Rainfall and Evapotranspiration [RCP]



Climate Futures Predicted Change		Annual Evapotranspiration (Percentage Change)						
		Large Decrease (< -4.6%)	Small Decrease (-4.6% to -1%)	No Change (-1% to +1%)	Small Increase (+1% to +4.6%)		Large Increase (> +4.6%)	
Annual Rainfall (Percentage Change)	Much Wetter (> +15%)				×			
								×
	Wetter (+5% to +15%)				×		×	×
					×		×	×
	Little Change (-5% to +5%)				×	×	×	×
					×		×	×
	Drier (-15% to -5%)				×	×	×	×
					×		×	×
	Much Drier (< -15%)							×
					×		×	×

Source: After https://www.climatechangeinaustralia.gov.au/en

Cell Legend:

2040 – RCP4.5 **[28 Models]**	**2090 – RCP4.5** **[28 Models]**
2040 – RCP8.5 **[29 Models]**	**2090 – RCP8.5** **[29 Models]**

Very Low Consensus (<10% of Models)

Low Consensus (10-33% of Models)

Moderate Consensus (33-66% of Models)

Regardless of the generally low consensus of CCiA Model predicted changes, the approach taken for this assessment has been to conduct a transient simulation for the prediction period perturbing rainfall recharge by -20% and +20% to represent postulated climate change scenarios.

These bounds have been used because rainfall reductions are typically magnified 2-4 times when converted to rainfall recharge ('rainfall elasticity in recharge'), as described in Barron *et al*. (2012).
In terms of evaporation as discussed in **Section 3.1.2**, despite future projections for evaporation changes, actual evapotranspiration is reasonably used in numerical groundwater modelling as there is not an assumed unlimited water supply (to evaporate).

As discussed in **Section 7.5.5**, the evapotranspiration rates are also reduced linearly with depth to ET extinction depths dependent on the lithology, mapped high, moderate and low potential GDE areas, and vegetation cover.

The effect of the postulated climate change scenarios has been assessed for the CQC Project groundwater take/inflow estimates. It was found that the average change in groundwater take/inflow over the life of the CQC Project varied as follows with the following changes:

- -20% rainfall recharge: average predicted take/inflows reduced on average by 15.7%.
- +20% rainfall recharge: average predicted take/inflows increased on average by 16.9%.

This conservative approach is considered appropriate particularly when considering the compounding uncertainties raised by Alluvium Consulting (2019) in relation to the use of short instrumental records:

> *The uncertainties associated with using short instrumental records are compounded because eastern Australia is subject to decadal epochs of enhanced/reduced drought frequency that is strongly related to large-scale ocean-atmosphere circulation patterns such as the El Niño/Southern Oscillation (ENSO) and the Interdecadal Pacific Oscillation (IPO) (see Section 3.2.1).*

> *Despite these insights into physical mechanisms that deliver hydroclimatic extremes to eastern Australia, the practical implications of time-varying risks of extreme climate events (including drought and water supply shortage), and how best to deal with them, are presently unclear (Kiem et al., 2016; Johnson et al., 2016). This is at least partially due to the fact that existing instrumental records do not capture enough cycles of multidecadal variability to give accurate insights into what is plausible.*

However, as demonstrated in **Section 3.1.1** (**Graphs 3-1, 3-2 and 3-3**), historic decadal variability is evident and the period of extended below average rainfall conditions (since early 2017 as shown on the cumulative rainfall residuals [**Attachment 8**]) provides baseline datasets to inform groundwater connectivity analysis during such climatic conditions (i.e. below average rainfall).

Furthermore, it is also noted that Alluvium Consulting (2019) presents key findings from the investigations completed in June 2017 for the Qld Government Department of Science, Information Technology and Innovation (DSITI) and SEQwater titled "*Learning from the Past – incorporating Palaeoclimate Data into Water Security Planning and Decision-Making*" which based on a review of a high-resolution and correlated (with Queensland rainfall) palaeoclimate records (pre-1900), found for example, although long dry periods are evident in the instrumental period, they are not unprecedented and the longest dry period in the instrumental record (8 years from 2000-2007) has actually been matched or exceeded several times prior to 1900.

Further consideration and discussion relating to past (calibration) and future prediction scenario uncertainties is provided in **Section 8.12.4**. It is relevantly noted that the penultimate stage of the peer review by AGE Consultants suggested, in contrast, reduced evapotranspiration extinction depths be investigated (**Section 8.11.6**) thereby considering climate variability for the numerical groundwater model forward predictions.

Sea Level Rise Projections

The Qld Government has adopted a single-value or single-projection approach for planning purposes and uses a projected 0.8 m sea level rise by 2100, which considers the IPCC Fifth Assessment Report. The 0.8 metre sea level rise value is based primarily on the median value of the RCP8.5 greenhouse gas emission scenario which is 'business as usual' where the current rate in the growth of greenhouse gas emissions remains the same. It also considers the projected variation in the local sea level rise rate of northern Australia.[xx]

The 0.8 m increase considered is within the range of modelled constant head boundary conditions considered as part of the uncertainty (sensitivity) analysis (**Sections 7.5.1, 8.11.3 and 8.12**).

For relative comparison to historic sea level rise (and fall) associated with the Holocene and Pleistocene epochs, refer also to **Section 4.6.1**.

8.11.6 Peer Review Additional Parameter Analysis

Additional parameter analysis has been completed based on the penultimate stage of the peer review (AGE Consultants, Stage 3, 7 May 2020), and included three (3) numerical model sensitivity runs [X, XI and XII]. In summary, the additional parameter analysis was completed to demonstrate:

- little to no consequences to drawdown extents and key metrics when applying a reduced evapotranspiration extinction depth in the model across the majority of mapped Cenozoic sediments;
- the effects on model predicted drawdown extents to the north-west and peak baseflow/leakage change (by relative comparison to the quantitative UA output bounds in **Attachment 11**), if the effective boundary condition is removed along Tooloombah Creek (i.e. stage = 0 m)[32]; and

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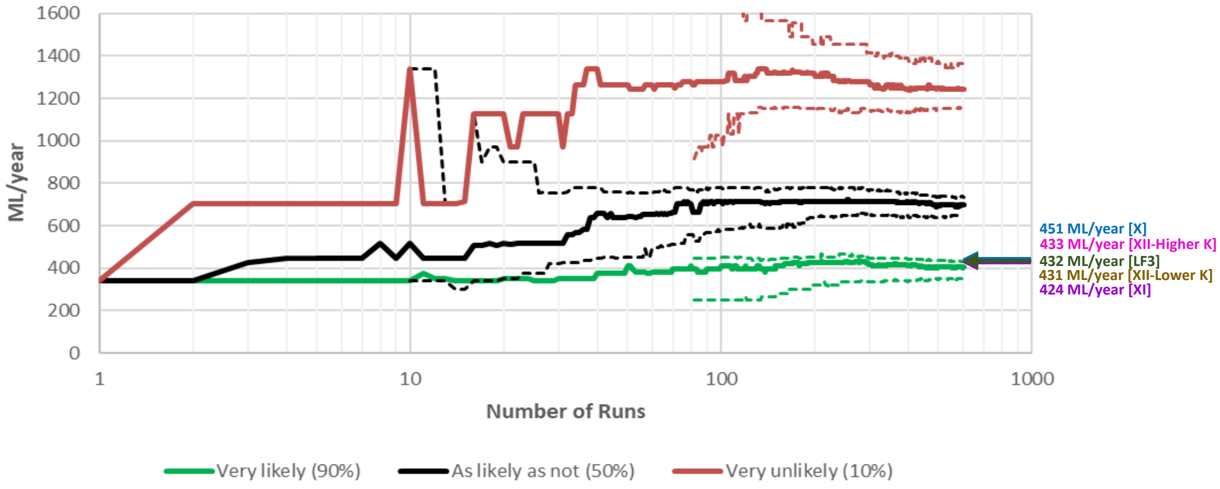
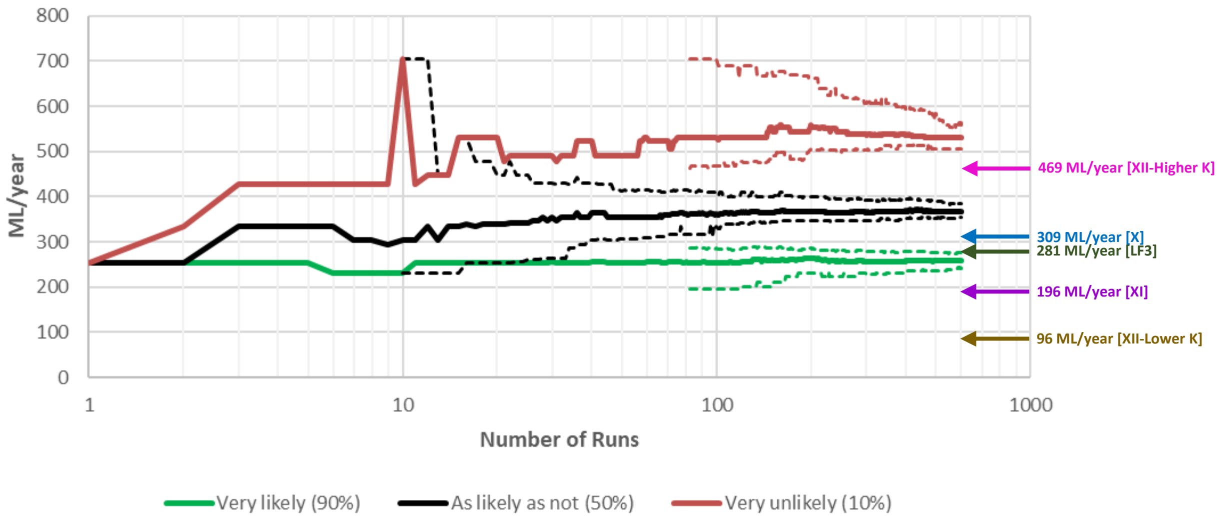
[32] Note that subsequent validation of pool elevations shows a better fit when stage +1 m is applied (**Section 7.8.1**).

- direct inflows from Tooloombah Creek to the open cut pit is unlikely in the long term and not evident in the model sensitivity, thereby supporting the concept of indirect (i.e. piston-like) groundwater movement effects.

The key model outputs of the additional parameter analysis are presented in **Attachment 18** and build further confidence in the numerical groundwater model (CQC-LF3) predictions and support the improved model classification (**Attachment 10**). And for relative comparison, the key metrics for each of the sensitivity scenarios (i.e. peak mine inflows [combined] and peak baseflow / leakage change for Tooloombah Creek) are also annotated on the quantitative UA 99.7% confidence intervals of probability of exceedance (**Attachment 11**) and provided on **Graphs 8-6 and 8-7**. Further details in relation to each model scenario is presented below.



Graph 8-6
99.7% Confidence Intervals of Probability of Exceedance – Peak Mine Inflows [Combined] – Additional Parameter Analysis Comparison with LF3



Graph 8-7
99.7% Confidence Intervals of Probability of Exceedance – Peak Baseflow/Leakage Change for Tooloombah Creek – Additional Parameter Analysis Comparison with LF3

(X) Model Scenario with Reduced ET Extinction Depth

Despite the qualitative justification presented in **Section 8.11.4** to apply the extinction depth across the Cenozoic sediments, primarily on the basis that the depth to groundwater table in many areas in the vicinity of the CQC Project are beyond 10 m (which was also consistent with the depth to groundwater maps presented on Figure 10-96 in CDM Smith [2018b]), AGE Consultants requested that the numerical model be re-run to quantify the changes.

Therefore, the 8 m evapotranspiration extinction depth was applied only where moderate and high potential GDEs had been mapped, and 3 m everywhere else within the model domain (**Figure 8-10**).

As shown in the key model outputs **(Attachment 18**), the maximum predicted drawdown extents are largely the same, and the peak mine inflow and baseflow/leakage change predictions are slightly higher than the CQC-LF3 results, but all well within the quantitative UA probability of exceedance of 50% (as likely as not) or approaching very likely (90%) (**Graphs 8-6 and 8-7**).

(XI) Model Scenario with Tooloombah Creek Boundary Condition Removed

For the purposes of comparison with the results presented for the CQC-LF3 model which applied a stage depth of 1 m along Tooloombah Creek Reach 2 (**Figure 7-4**), all RIV cells along the same reach were changed to a 0 m effective depth.

As shown in the key model outputs **(Attachment 18**), in the absence of a stage boundary condition in Tooloombah Creek Reach 2, the maximum predicted drawdown extents conservatively propagate to the north-west, generally along the strike of the coal measures. Changes in key metrics demonstrate the peak mine inflow predictions are substantially the same, and peak baseflow/leakage change predictions along Tooloombah Creek is less, and by comparison to the 99.7% confidence intervals of probability of exceedance is greater than very likely (>90%) (**Graph 8-6 and 8-7**).

It is also noted in **Section 7.8.1** (**Graph 7-7**) the surveyed pool levels along Tooloombah Creek in May 2020 (albeit two data points), provides a better fit with a stage depth of 1 m applied.

(XII) Model Scenario with Reduced and Enhanced River Bed Conductance

In response to the suggestion by AGE Consultants during the penultimate stage of the peer review that the model results could suggest the majority of water entering the open cut pit is either being drawn from the two nearby creeks, or would otherwise have discharged to them, both a reduced and enhanced river bed conductance scenario (with lower and higher hydraulic conductivity values applied respectively, i.e. 0.002 m/day and 0.05 m/day) was applied along Tooloombah Creek Reach 2 and Deep Creek Reach 1.

The largely unchanged predictions for annual mine inflow (**Attachment 18**) and peak inflow (**Graph 8-6**) demonstrate that direct inflows from Tooloombah Creek in the long term to the open cut pit is unlikely. This supports the concept of indirect (i.e. piston-like) groundwater movement effects, as the quantum of predicted inflows to the open cut drains still occurs from water stored in the immediately surrounding rocks. It is noted that the only differentials apparent on the graphs are during the first two years of the CQC Project, when the open cut pit is nearest Tooloombah Creek, and are only 3% to 6% different for the CQC-LF3 model predicted inflows.

As expected, with the application of a lower river bed conductance in the model for the sensitivity scenario, peak baseflow/leakage changes are much less.

8.12 PREDICTIVE MODEL – LIMITATIONS AND UNCERTAINTY MINIMISATION

Planned limitations and exclusions of a numerical groundwater model are largely defined by timeframes and availability of datasets for the calibration period and are discussed separately in **Section 7.7**.

Other known limitations relate to the need for balanced model discretisation for appropriate consideration of regional, local and feature-specific assessments. The following sub-sections describe the limitations and uncertainty minimisation for the forward predictions, recognising these planned limitations and exclusions.

As stated in the *Information Guidelines Explanatory Note: Uncertainty Analysis – Guidance for Groundwater Modelling within a Risk Management Framework* (Commonwealth of Australia, 2018), there are four sources of scientific uncertainty affecting groundwater model simulations:

- **Structural/Conceptual** - geological structure and hydrogeological conceptualisation assumptions applied to derive a simplified view of a complex hydrogeological reality (any system aspect that cannot be changed in an automated way in a model).
- **Parameterisation** - hydrogeological property values and assumptions applied to represent complex reality in space and time (any system aspect that can be changed in an automated way in a model via parameterisation).
- **Measurement Error** - combination of uncertainties associated with the measurement of complex system states (heads, discharges), parameters and variability (3D spatial and temporal) with those induced by upscaling or downscaling (site-specific data, climate data).
- **Scenario Uncertainties** - guessing future stresses, dynamics and boundary condition changes (e.g. mining, climate variability, land and water use change).

Each of the above has been considered during the development of the improved numerical groundwater model and the uncertainties are discussed in the following sections, with respect to overall objectives. Notably, and according to the Risk Management - Principles and Guidelines Standard (AS/NZS) ISO 31000:2009, risk is defined in terms of the effect of uncertainty on objectives.

It is also relevantly noted that the overall target model confidence level classification for the improved CQC Project numerical groundwater model is Class 2, and as demonstrated in **Attachment 10 (Tables A10-1 to A10-5)**, has been largely achieved and exceeded for several key criteria (based on Table 2-1 of Barnett *et al*., 2012), most notably:

- Groundwater head observations and drill hole logs are available across the model domain (**Sections 5.1, 5.2 and 5.4**), and at varying depths to allow vertical head gradient comparisons (**Section 7.7.4**), with a reasonable spatial coverage in the vicinity of the CQC Project and surrounds.
- Aquifer testing datasets are available to define key parameters for local aquifers and supported with laboratory core permeability and porosity testwork (**Section 5.6**).
- Scaled RMS (SRMS) errors (3.49% and 2.01%) and mass balance (maximum cumulative) closure errors (<0.01% and 0.08%) for steady state and transient calibration model runs are acceptable and are calibrated to heads (**Sections 7.7.4 and 7.7.5**).
- The length and temporal discretisation of the forward predictive model (i.e. 18 years, monthly) is not excessive to the length of the transient calibration period (2010-2019), in addition to the pre-calibration model variant (from 1919 to 2010) which includes approximately 45 years of historic mining operations in the Styx Coalfield.

Despite being a proposed mining area where groundwater systems are generally of limited potential, there are substantial datasets to draw upon which continue to be augmented with ongoing baseline data collection by CQCPL to satisfy regulator guideline requirements.

However, the area has been naturally limited by a lack of flow/flux (i.e. stream flow) data to calibrate against, primarily as extended below average rainfall conditions have occurred since early 2017 as shown on the cumulative rainfall residuals [**Attachment 8**]) and that other drainage features in the Deep Creek catchment are generally ephemeral in nature.

Thus, no reliable stream flow, baseflow or seep/spring flow data was available to calibrate at the time (to the end of September 2019) which is recognised as a planned limitation (**Section 7.7**). As a consequence, robust quantitative uncertainty analysis, scenario-based sensitivity analysis and other qualitative analysis has been undertaken (**Section 8.11**) and subsequent validation (**Section 7.8**).

As the CQC Project is yet to commence, model calibration to mine inflow or dewatering datasets is unable to be carried out. However, the pre-calibration modelling (**Graph 7-3**) undertaken does allow for the level of uncertainty to be reduced by demonstrating model consistency with mining stresses applied on the same stratigraphic sequence, which has been subject to flux changes, albeit without historical temporal groundwater level measurement.

8.12.1 Structural/Conceptual Uncertainties and Opportunities

The structural (geological) setting is detailed in **Section 4.1**. Conceptual uncertainties have been minimised, where possible, by utilising available geological mapping, cross-sections and historical mining records in the Styx Coalfield when constructing the groundwater model geometry (**Section 7.4**), recognising the mapped geological structures and faulting.

As described in **Section 7.3**, CQCPL's 2018 Geological Model was used to extract floor elevations for the Red, Blue, and Violet Seams in the near vicinity of the CQC Project open cut for the aggregated layers used in the improved groundwater model.

Beyond the 2018 CQC Geological Model, HydroAlgorithmics has used available drill logs from the groundwater monitoring investigations (**Section 5.1**) (including seam correlations at the historic mine workings at Ogmore and other exploration programs in the region; **Sections 3.4.5 and 3.4.6**) as well as structural, outcrop (including geological cross-sections; **Section 4.2.2**) and surficial geology mapping (**Sections 4.1 to 4.3**). Geological logs and descriptions available on the Government databases (**Section 5.2.2**) were also utilised to confirm or otherwise assign stratigraphic targets. Lateral connection groups have been used to create horizontal flow connections across the mapped faults. Sensitivity and uncertainty analyses explore alternative hydraulic properties along the faults; these are discussed in **Section 8.11.3.**

It is relevant to note that north-west of the historic workings near Ogmore, the model geometry is extrapolated and select layers pinched-out to the west where the Styx Coal Measures subcrop. Consequently, model layer assignment for the deep groundwater monitoring bores at WMP29C, WMP29D and WMP29E have been determined by a reasonable best fit rather than the actual depth of screens, for a spread of vertical pressure heads.

Structural/conceptual uncertainties have been specifically investigated by the geological structure (fault) zone analysis (with enhanced permeability) in **Section 8.11.3** and as shown on **Figure 8-8[b]** the differences in maximum predicted groundwater drawdown in Layer 2 is very localised whilst Layer 8 is negligible.

In terms of future opportunities, as described in **Section 10.1.9**, while a specific fault delineation program has not been undertaken, it is recommended that during the course of refined resource definition activities during mining operations, further mapping/delineation of the fault interface be undertaken (east of open cut).

That is, as mining progresses toward the east and further exploration drilling is conducted to continually improve and refine coal resource/reserve estimates, CQCPL could also potentially utilise the results of the drilling program to delineate the fault structure with increased precision[33].

As shown by the shape of the predicted drawdown contours and potential boundary effects, if for example the interface was to be located further east than that conceptualised and modelled, the drawdown contours could potentially extend further to the east (within the Styx Coal Measures) and consequently result in a reduction in the maximum extent toward the north. Therefore, consideration should be given to installing an additional groundwater monitoring bore (deep standpipe) to the north / north-east of Open Cut 2, but to the west of the mapped fault (e.g. between WMP05 and WMP10) in the Styx Coal Measures within the first three (3) years of the operation[34].

Whilst the new WMP31 VWP (**Attachment 4; Table A4-3**) provides validation of the expected presence of the fault (and potential barrier to flow) to the north-east/east, a location in the north would allow for early detection of the propagation of depressurisation effects in the deeper coal seams toward the north (and south of the historic mine workings) to compare with responses (if any) at WMP31 or trigger an adaptive management approach if required. The final location of the monitoring location may however be informed by the fault delineation drilling program.

The TEM survey (**Attachment 5**) has also been used to minimise the conceptual uncertainties regarding the extent and depths of Quaternary (Holocene) age units across the tenement, and importantly inferred the existing solid sandstone which was identified in the Tooloombah Creek rock bar. Such areas were therefore conservatively included in the numerical groundwater model geometry. With an in-depth understanding of the exploration drilling datasets and fluvial geomorphology, in combination with ongoing gauging station surface water level and flow data (at ToGS01) and alluvial groundwater datalogger (e.g. WMP04), there will be opportunities for the TEM survey datasets to be used to investigate future predicted changes at a localised scale.

More broadly, a review of the conceptualisation of the basement rock within the model domain (e.g. Back Creek Group and Boomer Formation) was undertaken as outlined in **Section 6.3.1**. Broad conceptualisation for the freshwater-saline water interface (using the Ghyben-Herzberg Relationship) as well as preliminary conceptualisations for eco-hydrogeological models were also developed to provide the opportunity for future review and refinement as necessary.

Finally, based on flood model predicted elevations in Tooloombah Creek by WRM Water & Environment (2020) near the pinch point between Mt Brunswick and Mt Mamelon (i.e. at approximately 25 mAHD), and use of the recently installed datalogger in WMP06 (recorded levels at approximately 16.9 mAHD, there is the opportunity for validation and comparison of future groundwater level responses (or lack thereof) and water quality changes at WMP06, recognising too the recent installation of the deeper screened WMP06D in the interburden of the Styx Coal Measures by CQCPL.

8.12.2 Parameterisation Uncertainties and Opportunities

Parameterisation uncertainties have been minimised initially through review of local aquifer testing, literature and prior numerical model parameterisation including systematic consideration of each hydrogeological unit represented in the improved numerical groundwater model (**Section 5.6**) and consideration of faulting and groundwater behaviour (**Section 5.6.8**).

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[33] As described in **Section 7.8.3**, subsequent exploration drill hole transects installed across Deep Creek (RDK7-12) has provided the opportunity to validate the modelled location of the interface between the Styx Coal Measures and Back Creek Group.

[34] In April 2020, CQCPL installed WMP21B to a total depth of approximately 95 m with screen targeting the overburden of the Styx Coal Measures in line with the recommendation.

As described in **Section 7.7.1**, both manual (initially) and automated calibration methods have been used, with manual calibration only used initially to assess model stability, before then being automated using the PEST suite of software (Doherty, 2015).

As discussed in **Section 6.3** and outlined in **Section 7.7.3**, the initial hydraulic properties targeted were assigned for each layer based on the updated conceptual groundwater model (**Table 6-4**). The initial anisotropy factor (x 10) and specific yield were assigned consistent with the core permeability (**Graph 5-9**) and porosity testwork (1.0%).

Appropriate ranges were then identified for different zones within each model layer based on the aquifer testing, literature review and prior modelling hydraulic properties compilation in **Section 5.6** and used as model allowable ranges (**Table 7-12**). Appropriate ratios (i.e. K_H / K_V) and magnitudes (i.e. specific yield >1%) were also considered.

The ranges (and where relevant log mean values) of adopted hydraulic properties at the end of the transient calibration are listed in **Table 7-12**. Storage properties applied within the model layers are also presented in **Table 7-13**.

A combination of parameter identifiability, sensitivity and qualitative analyses have been used in **Section 8.11** to identify bounds (or constraints) by available observations and then investigate if and/or how such parameters affect the model predictions. This recognises the challenge of non-uniqueness, and the possibility that multiple combinations of parameters may be equally good at fitting historical measurements, but at the same time has been used in support of the combination of parameters applied.

Robust quantitative uncertainty analysis was undertaken as detailed in **Section 8.11.2** and is presented in **Attachment 11**. Ranges and distributions applied to hydraulic properties as part of the quantitative uncertainty analysis included:

- lognormal distribution with 0.5 standard deviation for $K_{HORIZONTAL}$, S_s and $K_{HORIZONTAL}$/Infiltration% ratio;
- truncated lognormal distribution with 0.5 standard deviation for $K_{HORIZONTAL}/K_{VERTICAL}$ and a minimum of 1 (i.e. to maintain anisotropy greater than 1); and
- lognormal distribution with 0.25 standard deviation for S_y.

The quantitative uncertainty analysis approach was guided by the *Information Guidelines Explanatory Note: Uncertainty Analysis – Guidance for Groundwater Modelling within a Risk Management Framework* (Commonwealth of Australia, 2018).

As discussed in **Section 7.5.4**, and recognising opportunities for future model parameterisation validation (i.e. WMP06 datalogger, ToGS01 gauging station and substantial flood recharge events), the river bed conductance in Tooloombah Reach 2 could be factored accordingly to verify and history-match for periods.

8.12.3 Measurement Error Uncertainties and Opportunities

Opportunities to reduce measurement error uncertainties have been undertaken by:

- Use of LiDAR survey data captured by airborne laser scanning from a fixed wing aircraft as described in **Section 3.2**. Target survey accuracies were +/- 0.15 m (vertical) and +/- 0.45 m (horizontal) in areas of clear and open terrain. Importantly, as described in **Section 7.7.6**, the numerical groundwater model cell discretisation uses an average elevation with each model mesh cell (utilising the detailed LiDAR datasets).

- Detailed on-ground topographic survey measurements at key reference points at the CQC Project and surrounds by CCS Surveys Pty Ltd (2020) on behalf of CQCPL, including detailed cross-sections of Tooloombah Creek and Deep Creek (including control points) for the purposes of future flow gauging. Field capture of data for cross-sections and pool water elevation locations for validation was to an accuracy of under 0.050 m as presented in the *Central Queensland Coal Styx Coal South 10607-3-D3 Survey Report* (CCS Surveys Pty Ltd, 2020).
- The list of survey locations and measurements relating to groundwater (to allow comparison with tidal, alluvial groundwater bore, exploration/investigation bores and pool levels) are provided in **Table 8-10**.
- Review of select raw groundwater level and quality datasets which identified anomalies and past corrections which are noted where relevant (including alkaline pH considered to be due to deep borehole construction i.e. residual unset cement) and use of statistical summaries provided from the Orange Environmental Pty Ltd Database (7 January 2020).
- Groundwater monitoring and sampling undertaken by CQCPL with guidance from relevant standards and installation of new dataloggers (**Section 5.4.2**).
- Use of available stick-up measurements for all groundwater monitoring bores and landholder bores. Where no data was available a consistent (arbitrary) stick-up of 0.2 m was applied (i.e. assumes measurement from just above the ground surface).
- Use of representative BOM (Strathmuir) and site-specific (Mamelon Station) data to describe long-term rainfall trends, flood recharge events (2010-11, Cyclone Oswald and Cyclone Debbie) and average, to below average conditions in the near term.
- Utilising results of previous landholder bore survey (**Section 5.2.3**) and contemporary searches of Government databases to identify recently installed groundwater bores/users (**Section 5.2.2**).
- Removal of initial groundwater level recordings immediately post-construction from statistical datasets for steady state water levels as shown on the hydrograph (**Attachment 8**).
- Preparation of contour maps of measured and interpolated groundwater standing water levels, based on all available datasets with a reasonable spatial distribution (**Sections 5.1, 5.2 and 5.4**).
- Use of all available groundwater levels and pre-calibration model runs to investigate responses in temporal water level changes which could result from rainfall recharge or recovery effects from historical mine workings (**Graph 7-3**).

As recognised by the previous peer review, it is noted that several (WMP04D, WMP06, WMP12, WMP13, WMP20, WMP21D, WMP27) of the 31 groundwater monitoring locations are screened across two hydrogeological units (e.g. alluvium, regolith and/or coal measures) which does not allow separate responses to be investigated, nevertheless can still be considered with prudence[35].

Similarly, groundwater monitoring bores which record dry or standing water levels toward the bottom of the drill hole (e.g. WMP06, WMP07, WMP14, WMP17, WMP18, WMP21 and WMP27), may not allow for water quality sampling and/or observations to be taken at times. Opportunities for improvements to the groundwater monitoring program to help augment baseline datasets, validate model predictions and inform the future development of triggers are proposed in **Section 10.1**.

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[35] In April 2020, CQCPL installed additional locations at WMP06D and WMP21B to rectify for monitoring future responses in the vicinity of Tooloombah Creek (upstream) and Deep Creek (downstream).

Table 8-10
Detailed On-Ground Topographic Survey – Key Reference Points for Groundwater

Location	Easting	Northing	Surveyed Elevation (mAHD)	LiDAR Estimate (mAHD)	Potential Estimate Error	
Tidal and Alluvial Groundwater Bore Reference Points[+]						
Ogmore Road Bridge (At Permanent Survey Marker)	772344.98	7495972.81	7.248[b]	7.45^	-0.20 m	-2.7%
WMP29A (At Ground Level)	771295.88	7497386.73	11.283[a]	12.00	-0.72 m	-6.0%
WMP29A (Stick-up Height)	771295.88	7497386.73	12.263[a] [0.8 m]	13.00 [1.0 m]	-0.74 m	-5.7%
Pool Water Elevation Validation Points (May 2020)						
ToGS01 (At Rock Bar Pool Level)	772850.39	7490422.38	9.632[b]	9.72	-0.09 m	-0.9%
To2 (Pool Level)	772513.73	7489200.77	11.652[b]	-	-	-
DeGS01 (Pool Level)	774397.65	7490154.26	11.748[b]	-	-	-
De3 (Pool Level)	775982.31	7486691.96	20.876[b]	-	-	-
De2Pool1 (End of Pool Level)	774874.45	7485792.80	24.448[b]	-	-	-
Alluvial Groundwater Bore Reference Points[+]						
WMP04 (At Ground Level)	772865.29	7489358.66	27.255[a]	28.30	-0.10 m	-3.7%
WMP04 (Stick-up Height)	772865.29	7489358.66	28.735[a] [1.5 m]	29.50 [1.2 m]	-0.77 m	-2.6%
WMP05 (At Ground Level)	774487.46	7491624.55	15.51[a]	17.20	-1.69 m	-9.8%
WMP05 (Stick-up Height)	774487.46	7491624.55	16.52[a] [1.0 m]	18.20 [1.0 m]	-1.68 m	-9.2%
Exploration / Investigation Bores						
STX1901	772361.84	7488999.31	25.571[a]	-	-	-
STX1902	774594.95	7485924.11	29.208[a]	-	-	-
STX1901_B	772356.26	7489012.16	31.849[a]	31.80	0.05 m	0.15%
STX1901_C	772380.06	7489009.46	30.408[a]	30.40	0.01 m	0.03%
STX1902_C	774622.80	7485923.47	29.808[a]	29.80	0.01 m	0.03%
STX1902_B	774639.49	7485931.90	29.857[a]	29.90	0.04 m	-0.14%
STX1903G	773392.67	7486730.31	32.722[a]	-	-	-
STX1904G	772389.09	7487158.62	36.358[a]	-	-	-
STX1905	773353.33	7485402.42	35.67[a]	-	-	-

Source: After [a]WBG in CQCPL (2020a) and [b]CCS Surveys Pty Ltd (2020).

* At top of stake.

^ Preliminary desktop reading taken from LiDAR datasets at the bridge structure (prior to survey).

[+] Note: Subsequent verification survey by CCS Surveys Pty Ltd (2020), supports the comparison with the LiDAR estimates where available.

Finally, it is noted that groundwater levels (standpipe depth to groundwater) recordings have been used unadjusted in the reporting and model calibration targets (steady state and transient), and is considered appropriate particularly as freshwaters associated with surface water systems and adjacent alluvial aquifers are very limited. That is, density corrections (albeit small) have not been applied, but future groundwater model validation exercises could be used if necessary to investigate select groundwater monitoring bores which were to record very high salinities, should substantial head differentials be observed in the future. Nevertheless, the model calibration (**Section 7.7**) without adjustment is considered acceptable.

8.12.4 Scenario Uncertainties and Opportunities

Examples of scenario-based uncertainties and other analyses are detailed in **Sections 8.11.3, 8.11.4 and 8.11.5**, but it is also recognised that the mine plan progression (**Figure 8-1**) is based on the planned maximum mine schedule provided by CQCPL (**Table 8-1**). Importantly, robust quantitative uncertainty analysis was undertaken as detailed in **Section 8.11.2** and is presented in **Attachment 11**. Recommendations for annual monitoring review and reporting, including verification of the numerical groundwater model predictions, or updates to the numerical groundwater model (e.g. re-calibration, additional sensitivity analysis or revised forward predictions) are provided in **Section 10.9**.

9.0 POTENTIAL IMPACTS ON GROUNDWATER RESOURCES, DEPENDENT ASSETS AND ENVIRONMENTAL VALUES

The following sub-sections have been prepared cognisant of the DEHP TOR Guideline – Water[xxi] which lists possible water-related impacts typically associated with resource projects as follows:

- direct or indirect dewatering of hydrogeological units (refer to **Sections 8.4, 8.5 and 8.6**);
- the hydraulic properties of hydrogeological units - potential changes in storage, potential for physical transmission of water within and between units, effects of depressurisation due to gas extraction; and the leakage of contaminants from coal beds through hydrogeological units (refer to **Section 8.3**);
- hydrological interactions between water resources - surface water/groundwater connectivity, inter-aquifer connectivity and connectivity with sea water; and the extent of the cone of depression (refer to WRM Water & Environment [2020] and **Sections 3.3, 5.1, 8.5 and 8.6**);
- surface watercourse diversions (refer to WRM Water & Environment [2020] and Fluvial Systems Pty Ltd [2020] [**Attachment 6**]);
- direct and indirect impacts on ecological assets such as flora and fauna dependent on surface water and groundwater, springs and other GDEs (e.g. riparian vegetation, base flows in streams, wetlands) (refer to WRM Water & Environment [2020], and Eco Logical Australia Pty Ltd [2020a&b] and **Sections 3.5, 5.3, 5.4 and 8.7**);
- on water related assets due to operational and emergency discharges of water and waste water, from both a quality contamination and flow regime modification perspective (particularly saline water), including potential emergency discharges due to unusual events (refer to WRM Water & Environment [2020]);
- contamination of groundwater due to well stimulation techniques (not relevant, gas wells/fracking is not proposed for the CQC Project);
- subsidence and other effects from dewatering and depressurisation (including lateral effects) on surface topography, water related assets, groundwater and movement of water across the landscape and possible fracturing of and other damage to confining layers (refer to **Section 8.3**);
- long term impacts to water resources, erosion and fragmentation of water dependent species/ communities habitat through landscape modifications, for example, voids (including partial backfilling), onsite earthworks, roadway and pipeline networks (refer to WRM Water & Environment [2020], Engeny Water Management [2020], and Eco Logical Australia Pty Ltd [2020a&b] and **Sections 8.3.6 and 8.9**);
- release of contaminants to waters from wastes including tailings, mineral processing activities, waste rock dumps, sewage disposal, hazardous materials including fuels, process reagents, lubricants, detergents, explosives, solvents and paints and general waste (refer to RGS [2020] and WRM Water & Environment [2020]) and **Section 4.5**);
- release of contaminants to waters due to disturbance of rock and soils with potential to generate hazardous contaminants due to chemical reactions, including pyritic minerals, acid sulfate soil and sodic soils (refer to RGS [2020], WRM Water & Environment [2020] and **Sections 4.4, 4.5 and 4.6**);
- creation of mining voids (and final landforms) with water quality inconsistent with agreed uses (refer to WRM Water & Environment [2020] and **Sections 8.3.6 and 8.9**); and
- the cumulative impact of the proposal when all developments (past, present and/or reasonably foreseeable) are considered in combination (**Section 8.10**).

9.1 POTENTIAL IMPACTS ON GROUNDWATER QUANTITY AND ASSOCIATED SURFACE WATER FLOW REDUCTIONS

9.1.1 During Mining

Direct Groundwater Inflows – Styx Coal Measures

Up to the end of mining, there would be a continuous loss of groundwater from the Styx Coal Measures and to a lesser extent depressurisation of the underlying Permian Measures to the advancing open cuts. As shown on **Graph 8-1**, groundwater inflows steadily reduce to negligible inflows for the final years of the CQC Project as the backfilled spoil in the previously mined (down-gradient to the north and east) areas are recharged and recovering.

Changes in Local Groundwater Flow Directions

As mining progresses, the active open cut would act as a localised groundwater sink. This would cause a temporary change in groundwater flow direction, in places reversal of direction, until mining is completed and the groundwater system recovers. Model predicted head plots during the mining operation are shown on **Figures 8-3[a-d]**. The predicted changes in local groundwater flow directions over time are evident by comparison of the plots presented in **Attachment 15** with **Attachment 13**.

The long-term recovered groundwater flow pattern is discussed in **Section 9.1.2**.

Direct Groundwater Inflows - Alluvium

It is noted that the limited use and general absence of active groundwater users within ML 80187 (**Section 5.2**), the depth to groundwater table (**Section 5.4**), the typically saline nature of the groundwaters (**Section 5.5**) and the targeted groundwater investigations (**Attachments 5 and 7**) all confirm that the groundwater systems are not significant aquifers at the CQC Project. That is, the groundwater systems at the CQC Project are of limited potential.

However, when considering the environmental values and WQOs in **Section 6.2**, and the results of the TEM survey, the groundwater associated with the Qa units (AZ6) are of generally better water quality due to surface recharge/connectivity when compared to the Quaternary Pleistocene alluvium [Qpa] unit (CZ2), and therefore of relative greater environmental value.

The CQC Project open cut pits are approximately 150 m from Tooloombah Creek and Deep Creek.   No direct take (extraction) of the water from higher permeability surficial Quaternary alluvium (Qa) is proposed for the CQC Project.

As described in **Section 6.3.4**, clay is the most frequently encountered material within the Quaternary age sediment across the CQC Project area (i.e. Quaternary Pleistocene Alluvium) and is consistent with the findings of the TEM survey and observations of CQCPL’s geologists, whereby more permeable ‘Holocene’ Quaternary alluvium is restricted to rare deep cut infills and that no levees banks have formed along the watercourse margins (indicating overbank flooding [e.g. deposition beyond the channel] is rare).

Indirect Groundwater Inflows - Alluvium

Indirect leakage induced by the CQC Project from the alluvium/regolith can occur by:

- enhanced leakage from the alluvium/regolith to the underlying Early Cretaceous/Permian rock; and
- interruption of rainfall recharge to excavated alluvium/regolith.

As mining progresses, an increase in natural leakage of groundwater from the alluvium/regolith to the underlying Early Cretaceous/Permian rock would be expected and the predicted drawdown in the Cenozoic Deposits provided in **Section 8.5.2 and 8.5.3**. The removal (excavation) of alluvium/ regolith within the pit extent during mining would also reduce rainfall recharge temporarily but would resume upon backfilling and is discussed below.

Changes in Hydraulic Properties

As described in **Sections 8.3.2 and 8.3.3**, there would be a change in hydraulic properties across the open cut mining footprint from the ground surface where waste rock infills the excavations to the floor of the mined coal seams, as well as the out-of-pit emplacements during mining (notably those which remain post-mining). Thus, rainfall recharge is expected to be higher across the backfilled/placed waste rock material.

As waste rock would have a higher hydraulic conductivity than the natural (unbroken) material, there would be associated reductions in hydraulic gradients. Therefore, a flattening of hydraulic gradients is expected in the backfilled waste rock material and subtle mounding in the final out-of-pit emplacement landform.

Changes in Water Balance

The two main local surface water drainage systems near the CQC Project area are Deep Creek and Tooloombah Creek. The Styx River is located several kilometres downstream of the confluence of Deep Creek with Tooloombah Creek. The modelled groundwater-surface water interactions for specified reaches of Deep Creek, Tooloombah Creek and the Styx River are presented in **Section 7.7.6 (Graph 7-5)**.

The model predicted baseflow changes and/or enhanced leakage as a result of CQC Project along specified watercourse reaches for Deep Creek, Tooloombah Creek and the Styx River are presented in **Section 8.6**, and also considers other drainage features (i.e. Mamelon Creek [upstream west], Barrack Creek [upstream east] and the Broad Sound Fish Habitat Area [FHA-087] downstream north) for the purposes of assessment.

The results of the quantitative uncertainty analysis (**Section 8.11.2**) demonstrates that the CQC Project is too far away to have any discernible effects downstream on the Broad Sound Fish Habitat Area (Plan FHA-087) (**Table 8-8**). Based on the model predicted groundwater-surface water interactions and peak baseflow/ leakage changes for Barrack Creek (**Graph 8-3**) and Mamelon Creek (**Table 8-8**) respectively, there are no appreciable changes predicted for these drainage features as a consequence of the CQC Project.

As demonstrated by the analysis of the modelled ranges for Tooloombah Creek (**Table 7-17 and Graph 7-5**), and recognising the model discretisation (**Section 7.7.6**), as well as rock bar pooling (**Plate 4-2**) and surface water flows (**Graphs 3-6 and 3-7**), there is a complicated pattern of both natural leakage (from surface water flows) and potential interflow/baseflow over time (**Sections 6.3.3 and 6.1.1**; WMP06), which, when considering the magnitude of predicted water losses (< 0.009 m^3/s) (**Graph 8-4**) as a consequence of the indirect groundwater inflows from the associated alluvium relating to the 9.3 km length of the defined watercourse, is negligible when compared to stream flow volumes and the localised effects of surface water catchment excision by the CQC Project (**Table 9-1**). Nevertheless, refined analysis has been undertaken separately by WRM Water & Environment Pty Ltd (2020) and Eco Logical Australia Pty Ltd (2020a; 2020d).

The onset (and recovery) of gradual indirect effects of predicted drawdown over time are clearly shown on **Graph 8-4**, and readily explained by the proximity of the open cut initially to the watercourse, and subsequent backfill.

Table 9-1
Estimated (Maximum) Local Catchment Excision

Reach / Catchment		Maximum Catchment Change	
		During Mining	Post-Mining
Tooloombah Creek	Within Reach 2	0.97 km^2 [Runoff Capture]	-2.22 km^{2}* [Additional Runoff]
	% of Total Catchment Upstream of Deep Creek Confluence	0.26%	-0.60%
Deep Creek	Within Reach 1	16.9 km^2	2.22 km^2
	% of Total Catchment Upstream of Tooloombah Creek Confluence	5.62%	0.74%
Styx River	Upstream of Reach 2 & 3	17.17 km^2	Nil
	% of Total Catchment to Ogmore	2.50%	Nil

Source: WRM Water & Environment Pty Ltd (Email 10 March 2020).
* Additional catchment as a result of post-mining landform surface and up-catchment diversion structures (from Deep Creek catchment to Tooloombah Creek catchment).

Although the predicted changes for Deep Creek are comparable and/or less than those predicted for Tooloombah Creek (**Graph 8-3**), it is important to note that the modelled surface water-groundwater interactions (**Table 7-5**) are considered conservative given the fact that the reaches of Deep Creek in the vicinity of the CQC Project were dry (**Plates 3-10 to 3-12**), which if the predicted losses were applied in similar conditions would have no direct consequence on stream flow.

Recognising the model discretisation (**Section 7.7.6**), as well as surface water flows (**Graphs 3-8 and 3-9**), the magnitude of predicted water losses (0.005-0.006 m^3/s) (**Graph 8-3**) as a consequence of the indirect groundwater inflows from the associated alluvium relating to the 17.5 km length of the defined watercourse is negligible when compared to stream flow volumes and the localised effects of surface water catchment excision by the CQC Project (**Table 9-1**), nevertheless refined analysis has been undertaken separately by WRM Water & Environment Pty Ltd (2020) and Eco Logical Australia Pty Ltd (2020a;2020d).

9.1.2 Post Mine Closure / Equilibrium

In the long-term, all voids would be backfilled and groundwater levels would substantially recover over many decades as detailed in **Section 8.9**.

Some localised mounding is predicted to occur where the final landform surfaces are elevated above the existing surface, and the resulting net gain effects evident in the predicted changes in baseflows and/or lesser leakage in Tooloombah Creek and Deep Creek after approximately 150 years (**Graph 8-3**).

Changes in Local Groundwater Flow Directions

Post-mining model predicted head plots are shown on **Figures 8-5[a-c]**. The predicted changes in local groundwater flow directions over time are evident by comparison of the plots presented in **Attachment 15** with **Attachment 13**. The recovery and re-establishment of post-mining head gradients (flow direction) vectors to a new equilibrium are specifically shown on **Figure 8-6[a-f]**.

The long-term recovered groundwater flow pattern, as shown in on **Figure 8-6[c]** and **Figure 8-6[f]**, is similar regionally to the pre-mining flow pattern.

9.2 POTENTIAL IMPACTS ON GROUNDWATER QUALITY

9.2.1 During Mining

The CQC Project would use groundwaters that drain directly to the open cut pit sumps. The groundwaters would be pumped to holding dams, where water collected would be incorporated into the site water balance. Associated groundwaters accessed by the CQC Project would provide a beneficial industrial use, despite the brackish (saline) water quality of the Styx Coal Measures.

Changes in Local Groundwater Quality

The quality of the inflow water during mining would be a mixture of the qualities of the waters in source lithologies, primarily coal and the Styx Coal Measures, and to a lesser extent the Cenozoic deposits.

After mining is completed, and recovery gradually occurs within the backfilled spoil, the geochemistry of the waste rock (**Section 4.5**) would become a contributor to the water chemistry, however, it is recognised that rainfall recharge is expected to be higher across the backfilled/placed waste rock material and therefore contribute a greater proportion than any natural local material.

The chemical characteristics of existing groundwater for individual monitoring bores, and conceptualised hydrogeological units are summarised in **Sections 5.5, 6.1 and 6.2**. With the exception of a few shallow groundwater bores immediately adjacent to the watercourses, the groundwater quality within the tenement and surrounds is generally of poor quality, and of limited use, primarily on the basis of salinity. It is relevant to note that searches of the Government databases (**Table 5-7**) demonstrate that more broadly in the Styx River catchment groundwater users are in the Permian Measures and/or Volcanic units which appear to be not as poor a water quality as the Styx Coal Measures and Cenozoic Deposits (i.e. Quaternary Pleistocene Alluvium). Further discussion is provided in **Section 6.2** but based on the available groundwater quality datasets (**Sections 5.5.2 and 5.5.4**), the groundwaters within ML 80187 associated with the Styx Coal Measures and Quaternary Pleistocene Alluvium are generally unsuitable for stock watering.

Given the similarity of higher (albeit variable) salinity for the various source groundwaters, no appreciable change in groundwater salinity is expected as a consequence of mining.

The dissolved metal concentrations presented (where available) in **Tables 5-10, 5-11, 5-12, 5-14, 5-15 and 5-16** specifically target the parameters identified during the geochemical testwork outlined in (**Section 4.5**) including:

- Arsenic (As), Iron (Fe), Manganese (Mn) and Zinc (Zn) – as one sample suggested some (albeit slight) enrichment in the local geology when compared to the average crustal abundance; and
- Aluminium (Al), As, Molybdenum (Mo), Selenium (Se) and Vanadium (V) – where dissolved concentrations recorded warranted further consideration when kinetic leach column laboratory testing and multi-element composition analysis was compared to relevant assessment criteria.

As the advancing open cuts (until backfilled) would act as localised groundwater sinks during mining, there would be no deleterious effect on the beneficial uses of any groundwater sources.

Hydrocarbons and Other Chemicals

There is limited potential for groundwater contamination to occur as a result of hydrocarbon and other chemical contamination as: the depth to groundwater is typically greater than 10 mbgl; the transport, handling and storage of hydrocarbons and other chemicals would be in accordance with Australian Standards; and if a spill was to occur, immediate clean-up procedures would be enacted. Such controls are standard practice and a legislated requirement in Qld.

9.2.2 Post Mine Closure / Equilibrium

In the long-term, as all voids would be backfilled and groundwater levels would substantially recover over many decades by enhanced rainfall recharge/infiltration across the backfill spoil and emplacement areas, there is expected to be no appreciable change in groundwater quality as a result of the CQC Project. That is, insofar as to affect the existing beneficial use opportunities.

However, it is recognised (and evident in **Figures 8-5[a][i], 8-5[b][i] and 8-5[c][i]**) that the backfilled void would maintain a localised groundwater sink for several decades.

Whilst it is recognised that CDM Smith (2018k) relevantly concluded during the geochemical assessments (**Section 4.5**) that metal / metalloid concentrations in water extracts by RGS Environmental in 2012 were generally consistent across composition samples and therefore likely consistent with existing concentrations within the regional geology and associated aquifers, the kinetic leach column laboratory testwork results for net alkalinity and residual ANC indicate that the alkalinity continued to be at or greater than the initial values and the rock could be expected to continue to produce alkalinity commensurate with the high average ANC of the static laboratory testwork results.

But, based on the static and kinetic laboratory testwork undertaken, the salinity of the waste rock and other representative materials was moderate to low (with decreasing salinity) and relatively stable over the testing period (CDM Smith, 2018k). Nevertheless, a Mineral Waste Management Plan, including groundwater (seepage) monitoring program would be developed as outlined in **Section 10.3** to provide for appropriate groundwater quality management through, for example, select placement of spoil types and/or rejects at depth in-pit and below the long-term recovered heads to minimise the potential for oxidation processes as well as ongoing groundwater quality monitoring.

9.3 POTENTIAL IMPACTS ON ENVIRONMENTAL VALUES

Potential impacts on each of the environmental values outlined in **Section 6.2** are discussed below.

- **Aquatic Ecosystems** - As discussed in **Section 9.1.1**, refined analysis has been undertaken separately by WRM Water & Environment Pty Ltd (2020) and Eco Logical Australia Pty Ltd (2020a; 2020d) for surface waters. However, it is noted that groundwater levels are generally 10-30 mbgl in the Cenozoic sediments and separated from surface waters within the CQC Project disturbance footprint, limiting potential for groundwater to support GDEs and therefore aquatic ecosystems.
- **Irrigation –** As discussed in **Section 6.2.2**, groundwater is not currently used for irrigation on the Mamelon property and there are no known irrigation bores in the immediate vicinity. Entitlements exist to support agricultural activities (including irrigation) in the Styx River catchment but are sourced from surface waters. Although the magnitude of predicted water losses in Tooloombah Creek and Deep Creek (**Graphs 8-3 and 8-4**) as a consequence of the indirect groundwater inflows are considered to be negligible (**Section 9.1.1**), refined analysis has been undertaken separately by WRM Water & Environment Pty Ltd (2020) and Eco Logical Australia Pty Ltd (2020a; 2020d) for surface waters, albeit focussed on aquatic ecosystem environmental values.
- **Farm Supply / Use** - Groundwaters are not currently used for farm supply / use within ML 80187 and as discussed in the **Section 6.2.3** the poor water quality of the Styx Coal Measures and Quaternary Pleistocene Alluvium is generally unsuitable for such use. The predicted drawdown on private landholder bores is provided in **Table 8-4**. Only one private landholder bore (BH28 [McCartney {97864}]) is predicted to be impacted beyond the 5 m bore trigger threshold defined in the *Water Act 2000* for consolidated aquifers. All other private landholder bores (BH Series) are predicted to be below <0.5 m and would not exceed the 2 m bore trigger threshold defined in the *Water Act 2000* for unconsolidated aquifers.

- **Stock (Drinking) Water** - Based on the available groundwater quality datasets (**Sections 5.5.2 and 5.5.4**), the groundwaters within ML 80187 associated with the Styx Coal Measures and Quaternary Pleistocene Alluvium are generally unsuitable for stock watering. Given the similarity of higher (albeit variable) salinity for the various source groundwaters, no appreciable change in groundwater salinity is expected as a consequence of mining. The predicted drawdown on private landholder bores is provided in **Table 8-4**. Only one private landholder bore (BH28 [McCartney {97864}]) is predicted to be impacted beyond the 5 m bore trigger threshold defined in the *Water Act 2000* for consolidated aquifers. All other private landholder bores (BH Series) are predicted to be below <0.5 m and would not exceed the 2 m bore trigger threshold defined in the *Water Act 2000* for unconsolidated aquifers.

- **Human Consumer** – As discussed in **Section 6.2.6**, based on the relatively poor water quality of groundwaters in the open cut extent and basement rocks within ML 80187 (**Sections 5.5.2, 5.5.4 and 5.5.5**), no groundwaters that report to the sumps within the open cut are anticipated to be suitable for human consumption. As discussed in **Section 9.1.1**, refined analysis has been undertaken separately by WRM Water & Environment Pty Ltd (2020) and Eco Logical Australia Pty Ltd (2020a; 2020d) for surface waters, albeit focussed on aquatic ecosystem environmental values.

- **Drinking Water** - As described above in **Section 6.2.6**, no groundwaters that report to the sumps within the open cut are anticipated to be suitable for human consumption. Given the similarity of higher (albeit variable) salinity for the various source groundwaters, no appreciable change in groundwater salinity is expected as a consequence of mining. The predicted drawdown on private landholder bores is provided in **Table 8-4**. Only one private landholder bore (BH28 [McCartney {97864}]) is predicted to be impacted beyond the 5 m bore trigger threshold defined in the *Water Act 2000* for consolidated aquifers. All other private landholder bores (BH Series) are predicted to be below <0.5 m and would not exceed the 2 m bore trigger threshold defined in the *Water Act 2000* for unconsolidated aquifers.

- **Industrial Use** - The CQC Project would utilise groundwaters that report to the sumps within the open cut in ML 80187. Such groundwaters are anticipated to be of relatively poor water quality (**Sections 5.5.2, 5.5.4 and 5.5.5**) however would be suitable for industrial use and therefore preferentially used in the mine site water balance.

- **Aquaculture, Primary Recreation, Secondary Recreation and Visual Recreation** - Groundwaters are not currently used for such purposes within ML 80187, nor known to be used for such purposes in proximity to the CQC Project, therefore potential impacts on EVs are not considered, nor WQOs proposed as outlined in **Section 6.2**.

- **Cultural and Spiritual Values** – As discussed in **Section 6.2.12**, there are no known EVs for cultural or spiritual values within ML 80187, nor known in proximity to the CQC Project. Therefore, potential impacts on such EVs are not considered, nor WQOs proposed as outlined in **Section 6.2.**

10.0 MONITORING, MANAGEMENT, LICENSING, REVIEW AND MITIGATION MEASURES

10.1 PROPOSED GROUNDWATER MONITORING PROGRAM

A draft of the proposed groundwater monitoring program including specific components to address the matters raised in the Government submissions are provided below. The groundwater monitoring network would be finalised for staged installation (where required) prior to commencement of relevant mining activities, nevertheless the proposed network is as shown on **Figure 10-1**.

Groundwater monitoring and sampling would be undertaken with guidance from the following:

- *Groundwater Sampling and Analysis – A Field Guide* (Geoscience Australia, 2009);
- *Sampling, Part 1: Guidance on the Design of Sampling Programs, Sampling Techniques and the Preservation and Handling of Samples* (AS/NZS 5667.1:1998); and
- *Sampling, Part 11: Guidance on Sampling of Groundwaters* (AS/NZS 5667.11:1998).

Groundwater monitoring and analysis would be performed by an appropriately qualified person. An outline of the specificity required for the final groundwater monitoring program, based on a review of the *Guideline Mining: Model Mining Conditions* (ESR/2016/1936) as well as existing coal mining operations and contemporary Qld mining project approvals in the Bowen Basin, is provided in the draft environmental authority (EA) conditions in **Section 10.10**.

Importantly, the DES' recommendations for quarterly groundwater monitoring has been adopted for the program, with the inclusion of an administrative mechanism to reduce the sampling frequency at an appropriate time in the future (e.g. when baseline triggers are agreed) where it can be demonstrated/ supported. Nevertheless, sampling may be undertaken on a more frequent basis in advance of relevant mining activities to augment baseline datasets if and as required.

10.1.1 Groundwater Pit Inflow Monitoring Program

Groundwater inflows to the advancing open cut mining operations would be directed and collected in pit sumps, along with incidental rainfall and runoff and/or seepage through backfilled pit areas. Water level and water quality analysis in pit sumps would be undertaken periodically (e.g. quarterly) and volumes of water extracted recorded, where practicable, or estimated (given the relatively low groundwater inflows predicted). Any observations of unexpected or significantly increased groundwater inflows (or sharp salinity increases) directly to the open cut pit should be recorded.

A site water balance review would be undertaken on an annual basis to monitor the status of accumulation of water in the pit sumps (including groundwater inflows), storage (and quality) changes, suitability for water use and consumption (e.g. dust suppression, CHPP, etc.). The site water balance review would be used to adapt and optimise water management performance and enable corrective actions to be implemented if and as required. For example, should direct groundwater inflows be observed and recorded from higher permeability surficial Quaternary alluvium (Qa) (of generally better (surface water) quality when compared to the Quaternary Pleistocene alluvium [Qpa] unit) then contingency procedures can be triggered to remedy.

10.1.2 Private Landholder Bores

As described in **Section 8.7.1**, only one private landholder bore (BH28 [McCartney {97864}]) is predicted to be impacted beyond the 5 m bore trigger threshold defined in the *Water Act 2000* for consolidated aquifers.

A baseline assessment cognisant of the Qld *Guideline Baseline Assessments* (DES, 2017) would therefore be required.

No other private landholder bores identified in the vicinity of the CQC Project are predicted to be impacted by the open cut pit extent and associated drawdown/depressurisation greater than the bore trigger thresholds (2 m and 5 m) in unconsolidated or consolidated aquifers respectively as defined in the *Water Act, 2000*. Nevertheless, considering the results of the Uncertainty Analysis, it is recommended that periodic (e.g. seasonal/quarterly, or less frequently if otherwise agreed) water level monitoring be conducted during the operational life of the CQC Project to confirm / verify the predictions toward the north (e.g. BH24 and BH01X or BH16) and/or if necessary conduct an investigation to determine if there are other attributable and/or anthropogenic impacts, in conjunction with the existing groundwater monitoring network.

If following an investigation, groundwater drawdown at a private landholder bore was considered attributable to other and/or anthropogenic impacts, the monitoring frequency may be reduced accordingly.

Preliminary groundwater level and quality triggers are discussed further in **Sections 10.1.10 and 10.1.11.**

10.1.3 Styx River – Tide Monitoring at Ogmore Road Bridge

The depth to water surface (**Section 3.3.2**) from the permanent survey marker (PSM) at the Ogmore Road Bridge deck (Nameplate: Main Roads, 2006) (**Plate 10-1**) would continue to be recorded periodically to validate the range of predicted stage water levels in the Styx River undertaken as a component of the uncertainty analysis (i.e. range of constant head boundary conditions considered).

Opportunistic readings from the adjacent flood gauge boards would also be undertaken following larger rainfall runoff / flood events which would provide comparable datasets to complement the stream gauging station records on Deep Creek and Tooloombah Creek further upstream (**Sections 10.1.4 and 10.1.5**).

Readings would be converted to absolute reference level (mAHD) from the permanent survey marker (approximately 1.3 m above the base of the bridge deck) on the kerb structure (approximately 0.35 m above the pavement[36]) on the north-west side of the bridge crossing, to then allow ongoing comparisons and correlations to the Broad Sound tidal gauges (**Section 3.3.1**) and nearby alluvial groundwater level measurements (i.e. WMP29A datalogger).

Plate 10-1
Ogmore Road Bridge Crossing at Styx River and Permanent Survey Marker
[*Source: WRM Water & Environment, October 2019*]

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[36] Detailed survey indicates an elevation of 7.25 mAHD at the PSM (CCS Surveys Pty Ltd, 2020) (**Section 8.12.3**).

10.1.4 Tooloombah Creek – Surface Water Flow Gauging and In-Stream Pools

Surface water level and flow measurements would continue to be recorded at the stream flow ALS Gauging Station (No. 330451) (ToGS01) on Tooloombah Creek (**Plate 10-2**). Cross section survey and identification of flow control points (CCS Surveys Pty Ltd, 2020; Central Queensland Coal Pty Ltd, 2020) and preliminary rating curve (WRM Water & Environment, 2020) has been developed for the stream gauge at Tooloombah Creek which is rock bar controlled. The rating curve would be subject to review following future rainfall runoff / flood events.

Plates 10-2
Tooloombah Creek Surface Water
Flow Gauging Station (No. 330451) (ToGS01)

Plate 10-3
Deep Creek Surface Water
Flow Gauging Station (No. 330452) (DeGS01)

It is understood that other waterholes and intermittent pools which exist along the lower reach of Tooloombah Creek would be subject to ongoing observation as part of the GDEMMP and REMP (**Sections 10.5 and 10.6**).

Whilst recommendations for additional upstream surface water monitoring have been suggested by the IESC in previous advice it is not considered necessary for flow monitoring, particularly given the comparatively large upper sub-catchments of Tooloombah Creek (approximately 367.7 km^2 total at the existing stream gauge on Tooloombah Creek) when compared to CQC Project development footprint within the Tooloombah Creek sub-catchment (approximately 0.2 km^2) (i.e. <0.1%). Nevertheless, an additional upstream surface water sampling point has been proposed (To4) (**Figure 3-7**).

10.1.5 Deep Creek – Surface Water Flow Gauging and In-Stream Pools

Surface water level and flow measurements would continue to be recorded at the stream flow Gauging Station (No. 330452) (DeGS01) on Deep Creek (**Plate 10-3**) (**Figure 3-7**).

It is understood that other waterholes and intermittent pools which exist along the lower reach of Deep Creek would also be subject to ongoing observation as part of the GDEMMP and REMP (**Sections 10.5 and 10.6**).

Similar to Tooloombah Creek, whilst recommendations for additional upstream surface water monitoring have been suggested by the IESC in previous advice it is not considered necessary for flow monitoring, particularly given the comparatively large upper sub-catchments of Deep Creek, including Barrack, Brussels and Brumby Creeks (approximately 281.9 km^2 total at the existing stream gauge on Deep Creek) when compared to CQC Project development footprint within the lowest reach of Deep Creek sub-catchment (approximately 10.5 km^2) (i.e. 3.7%).

10.1.6 Wetlands 1 & 2

Monitoring of existing groundwater monitoring bores (WMP25 and WMP27), albeit at depth below the ground surface (in excess of 10 m), would continue at Wetlands 1 and 2 (**Figure 5-1[b]**). As described in **Section 8.7.2**, maximum drawdown predicted at WMP25 and WMP27 is 2.7 m and 1.9 m respectively. Consideration of other monitoring (hydrological and/or ecological) of Wetlands 1 and 2 would be undertaken as described in the GDEMMP (**Section 10.5**).

Preliminary groundwater level triggers are proposed for WMP25 and WMP27 in **Section 10.1.10**.

10.1.7 Quaternary Alluvium, Pleistocene Alluvium / Regolith and Styx Coal Measures

The existing groundwater monitoring network in the Cenozoic deposits and Styx Coal Measures would continue generally as outlined and discussed in **Sections 5.1.1, 5.1.2, 5.5.1, 5.5.2 and 5.5.4**, but would be subject to ongoing review and rationalisation as baseline dataset requirements are fulfilled, and/or if sampling was to continue to demonstrate bores are effectively dry.

The preliminary list proposed is as outlined in the draft Environmental Authority Condition Table E1 (**Section 10.10**) which may for example in the long term be rationalised to the following (**Figures 5-1[a&b]**):

- Quaternary Alluvium (WMP05; WMP21; WMP29A) *[as well as Landholder Monitoring Bore BH16*];
- Quaternary Pleistocene Alluvium / Regolith (WMP02; WMP04; WMP06; WMP08; WMP12; WMP17; WMP18, WMP25, WMP26, WMP29B); and
- Styx Coal Measures (WMP04D; WMP08D; WMP10; WMP11D; WMP13; WMP14; WMP17D; WMP18D; WMP21D; WMP22A; WMP22B; WMP23A; WMP24; WMP28; WMP29C; WMP29D).

Consideration should be given to installing an additional groundwater monitoring bore (deep standpipe) to the north / north-east of Open Cut 2, but to the west of the mapped fault (e.g. between WMP05 and WMP10) within the first three (3) years of the operation[37]. Whilst the new WMP31 VWP would provide validation of the expected presence of the fault (and potential barrier to flow) to the north-east/east, a location in the north would allow for early detection of the propagation of depressurisation effects in the deeper coal seams toward the north (and south of the historic mine workings) to compare with responses (if any) at WMP31 or trigger an adaptive management approach if required.

The final location of the monitoring location could be informed by the fault delineation drilling program described in **Section 10.1.9** to ensure installation west of the fault structure.

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[37] In April 2020, CQCPL subsequently installed WMP21B to a total depth of approximately 95 m with screen targeting the overburden of the Styx Coal Measures.

To continue to inform the level of groundwater connectivity (or lack thereof) at WMP06 in the vicinity of Tooloombah Creek as discussed in **Section 6.3.3**, in April 2020 CQCPL installed a datalogger at WMP06, and installed an additional deeper standpipe (WMP06D) targeting the underburden of the Styx Coal Measures for future groundwater model validation purposes, and relative comparisons to WMP06 and ToGS01.

10.1.8 Back Creek Group (West)

The groundwater monitoring network in the Back Creek Group west of the subcrop of the Styx Coal Measures would continue generally as outlined in **Sections 5.1.3 and 5.5.5.**

The preliminary list proposed is as outlined in the draft Environmental Authority Condition Table E1 (**Section 10.10**) including (**Figures 5-1[b]**): WMP16; WMP16D, WMP19; WMP19D; WMP20; WMP20D; WMP22C and WMP29E.

10.1.9 Back Creek Group (including Boomer Formation) (East) / Fault Delineation

As described in **Sections 5.1.3 and 5.4**, a new VWP targeting the basement aquifers in a north-east drill hole (WMP31) in the Permian Measures east of the fault was installed in December 2019. Details of the new VWP installation is provided in **Table 5-5** and datalogger records to date are shown on the hydrograph in **Attachment 8**. Datalogger recordings would continue to be downloaded periodically at WMP31.

During the sampling campaign for laboratory core permeability testwork by GES (2020) (**Attachment 9**), drill core was unable to be sourced for the Back Creek Group (Permian Measures) from historic exploration core trays nor more recent drill campaigns (i.e. WMP31). As described in **Section 4.2.1**, a second drill hole (WMP32) was also proposed, but was subsequently installed adjacent to WMP31 (WMP32^{A}) to provide the opportunity for core sampling. It is recommended that to support future model validation (i.e. Layer 12 hydraulic properties), and with consideration of the parameter identifiability analysis in **Section 8.11.1**, laboratory core permeability testwork be conducted on representative site-specific samples in the Back Creek Group at the CQC Project, or aquifer testing at WMP32^{A}.

As discussed in **Section 10.1.7**, consideration should be given to installing an additional groundwater monitoring bore (deep standpipe) to the north / north-east of Open Cut 2, but to the west of the mapped fault (e.g. between WMP05 and WMP10) within the first three (3) years of the operation. Whilst the new WMP31 VWP would provide validation of the expected presence of the fault (and potential barrier to flow) to the north-east/east, a location in the north would allow for early detection of the propagation of depressurisation effects in the deeper coal seams toward the north (and south of the historic mine workings) to compare with responses (if any) at WMP31 or trigger an adaptive management approach if required.

While a specific fault delineation program has not been undertaken, it is recommended that during the course of refined resource definition activities during operations, further mapping/delineation of the fault interface be undertaken (east of open cut). That is, as mining progresses toward the east and further exploration drilling is conducted to continually improve and refine coal resource/reserve estimates, CQCPL could also potentially utilise the results of the drilling program to delineate the fault structure with increased precision[38]. Thus, installation of a deep standpipe for future validation monitoring at the originally proposed WMP32 location (WMP32^{B}) may assist.

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[38] It is noted that CQCPL has subsequently undertaken further fault investigations and reported in a memorandum dated 15 May 2020 (CQCPL, 2020b), which combined with recent exploration drill hole program results provides evidence to support the extension of the mapped fault structure to the south.

10.1.10 Groundwater Level Triggers

Groundwater drawdown predictions at each groundwater monitoring bore (and exploration drill holes) and individual landholder bores are presented in **Graph 8-2** and **Graph 8-5**.

Preliminary triggers have been developed at each groundwater monitoring bore reflecting either a proportion (e.g. approximately 75%) of the maximum predicted groundwater drawdown, or where less than 2 m, a default trigger in the unconsolidated aquifers of 2 m, and a default trigger in the consolidated aquifers of 5 m.

For the purposes of comparison and opportunities for future model validation (**Section 10.9**) and/or adaptive management, the predicted drawdown after approximately 3 years is also provided for each groundwater monitoring bore, where less 75% of the maximum predicted drawdown. The preliminary groundwater level triggers developed for select groundwater monitoring bores are presented in **Table 10-1** and have been used to inform the draft EA conditions (**Section 10.10**).

Table 10-1
Preliminary Groundwater Level Drawdown Triggers for Investigation

Bore Number / Reference (Figure 10-1)		Preliminary Groundwater Level Investigation Trigger (Approximate)			Comparison with 3 Year & Maximum Predicted Drawdown (m)
		Relative Drawdown Trigger (m)^	Absolute Trigger Level (mAHD)*	Approximate Depth (mbTOC)	
WMP02	CMB16	<2.0 m$^{\#}$	6.2 mAHD	19.5 mbTOC$^{\sim}$	[<0.5 m; 1.1 m] **To Dry**
WMP04	CMB13	7.0 m$^{\#}$	9.9 mAHD	19.6 mbTOC$^{\sim}$	[9.8 m; 19.9 m] **To Dry**
WMP04D	CMB14	**13.4 m** [Y3] **16.2 m** [75%Max]	3.3 mAHD / 0.5 mAHD	25.9 mbTOC / 28.7 mbTOC	[**13.4 m; 21.6 m**]
WMP05	CMB01	2.0 m	7.9 mAHD	10.3 mbTOC	[<0.5 m; 1.6 m] ***< 2.0 m***
WMP06	-	<2.0 m$^{\#}$	15.6 mAHD	19.1 mbTOC$^{\sim}$	[0.6 m; 0.9 m] **To Dry**
WMP07	CMB08	<2.0 m$^{\#}$	69.8 mAHD	61 mbTOC$^{\sim}$	[<0.5 m; 2.4 m] **To Dry**
WMP08	RMB06	2.0 m	31.4 mAHD	13.1 mbTOC	[<0.5 m; <0.5 m] ***< 2.0 m***
WMP08D	RMB07	2.0 m	31.9 mAHD	12.6 mbTOC	[<0.5 m; <0.5 m] ***< 2.0 m***
WMP09	CMB07	2.0 m [Y3] **2.9 m** [75%Max]	24.4 mAHD / 23.5 mAHD	14.2 mbTOC / 15.1 mbTOC	[<0.5 m; **3.8 m**]
WMP10	CMB06	2.0 m [Y3] 8.7 m$^{\#}$	17.6 mAHD / -14.0 mAHD	12.5 mbTOC / 19.2 mbTOC$^{\sim}$	[<0.5 m; 44.8 m] **To Dry**
WMP11	-	2.0 m	3.9 mAHD	16.0 mbTOC	[<0.5 m; <0.5 m] ***< 2.0 m***
WMP11D	RMB03	2.0 m	4.4 mAHD	15.5 mbTOC	[<0.5 m; 0.5 m] ***< 2.0 m***
WMP12	CMB15	<2.0 m$^{\#}$	7.9 mAHD	19.1 mbTOC$^{\sim}$	[0.6 m; 2.5 m] **To Dry**
WMP13	RMB01	2.0 m	2.2 mAHD	17.1 mbTOC	[<0.5 m; <0.5 m] ***< 2.0 m***

Table 10-1 (Continued)
Preliminary Groundwater Level Drawdown Triggers for Investigation

Bore Number / Reference		Preliminary Groundwater Level Investigation Trigger (Approximate)				Comparison with 3 Year & Maximum Predicted Drawdown (m)
		Relative Drawdown Trigger (m)^		Absolute Trigger Level (mAHD)*	Approximate Depth (mbTOC)	
WMP14	CMB11	<2.0 m$^{\#}$		13.2 mAHD	19.1 mbTOC$^{\sim}$	[0.9 m; 1.3 m] **To Dry**
WMP15	CMB09	2.0 m [Y3]	**5.3 m** [75%Max]	31.2 mAHD / 27.9 mAHD	13.3 mbTOC / 16.6 mbTOC	[<0.5 m; **7.1 m**]
WMP16	RMB10	2.0 m		18.2 mAHD	24.4 mbTOC	[<0.5 m; <0.5 m] ***< 2.0 m***
WMP16D	RMB11	2.0 m		15.7 mAHD	26.9 mbTOC	[<0.5 m; <0.5 m] ***< 2.0 m***
WMP17	RMB04	<2.0 m$^{\#}$		29.0 mAHD	12.8 mbTOC$^{\sim}$	[<0.5 m; 1.1 m] **To Dry**
WMP17D	RMB05	2.0 m		29.2 mAHD	14.2 mbTOC	[<0.5 m; 1.3 m] ***< 2.0 m***
WMP18	CMB04	<2.0 m$^{\#}$		16.7 mAHD / -16.2 AHD	12.8 mbTOC$^{\sim}$	[1.0 m; 46.5 m] **To Dry**
WMP18D	CMB05	2.0 m [Y3]	9.2 m$^{\#}$	14.3 mAHD / -18.9 mAHD	16.8 mbTOC / 23.9 mbTOC$^{\sim}$	[1.3 m; 46.9 m] **To Dry**
WMP19	RMB08	2.0 m		26.0 mAHD	15.7 mbTOC	[<0.5 m; <0.5 m] ***< 2.0 m***
WMP19D	RMB09	2.0 m		25.8 mAHD	15.8 mbTOC	[<0.5 m; 1.0 m] ***< 2.0 m***
WMP20	RMB12	<2.0 m$^{\#}$		21.8 mAHD	21.0 mbTOC$^{\sim}$	[<0.5 m; <0.5 m] **To Dry**
WMP20D	RMB13	2.0 m		21.9 mAHD	21.5 mbTOC	[<0.5 m; <0.5 m] ***< 2.0 m***
WMP21	CMB02	<2.0 m$^{\#}$		11.9 mAHD / 5.1 mAHD	10.6 mbTOC$^{\sim}$	[0.9 m; 11.7 m] **To Dry**
WMP21D	CMB03	**2.1 m** [Y3]	7.3 m$^{\#}$	9.2 mAHD / 4.0 mAHD	17.3 mbTOC / 22.5 mbTOC$^{\sim}$	[2.1 m; 13.4 m] **To Dry**
WMP22A	CMB17	15.3 m$^{\#}$		(-22.9 mAHD) / -34.6 mAHD	30.4 mbTOC$^{\sim}$	[49.6 m; 50.5 m] **To Dry**
WMP22B	CMB18	41.2 m$^{\#}$		(-22.9 mAHD) / -44.7 mAHD	56.3 mbTOC$^{\sim}$	[59.6 m; 64.4 m] **To Dry**
WMP22C	CMB19	**12.4 m** [Y3]	**27.6 m** [75%Max]	7.4 mAHD / -7.8 mAHD	22.9 mbTOC / 38.1 mbTOC	[**12.4 m**; **36.7 m**]
WMP23A	-	2.0 m [Y3]	**12.0 m** [75%Max]	24 mAHD / 14 mAHD	13.2 mbTOC / 23.2 mbTOC	[<0.5 m; **16.0 m**]
WMP23B	-	5.0 m [Y3]	**20.3 m** [75%Max]	31.9 mAHD / 16.6 mAHD	5.4 mbTOC / 20.7 mbTOC	[<0.5 m; **27.1 m**]
WMP24	CMB22	**4.5 m**		10.4 mAHD	9.5 mbTOC	[**4.5 m**; **5.3 m**]
WMP25 [Wetland 1]	CMB10	2.0 m		32.0 mAHD	12.8 mbTOC	[<0.5 m; **2.7 m**]
WMP26	CMB23	**5.3 m** [Y3]	5.6 m$^{\#}$	7.3 mAHD / 7.0 mAHD	20.8 mbTOC / 21.0 mbTOC	[5.3 m; 26.7 m] **To Dry**

Table 10-1 (Continued)
Preliminary Groundwater Level Drawdown Triggers for Investigation

Bore Number / Reference		Preliminary Groundwater Level Investigation Trigger (Approximate) Relative Drawdown Trigger (m)^	Absolute Trigger Level (mAHD)*	Approximate Depth (mbTOC)	Comparison with 3 Year & Maximum Predicted Drawdown (m)
WMP27 [Wetland 2]	CMB24	<2.0 m[#]	11.0 mAHD	21.4 mbTOC[~]	[1.4 m; 1.9 m] **To Dry**
WMP28	CMB25	<2.0 m[#]	7.6 mAHD	12.6 mbTOC[~]	[3.7 m; 4.6 m] **To Dry**
WMP29A	RMB14	2.0 m	1.4 mAHD	11.5 mbTOC	[<0.5 m; <0.5 m] ***< 2.0 m***
WMP29B	RMB15	2.0 m	1.3 mAHD	11.7 mbTOC	[<0.5 m; <0.5 m] ***< 2.0 m***
WMP29C	RMB16	5.0 m	-6.6 mAHD	19.6 mbTOC	[<0.5 m; <0.5 m] ***< 5.0 m***
WMP29D	RMB17	5.0 m	-14.1 mAHD	27.0 mbTOC	[<0.5 m; <0.5 m] ***< 5.0 m***
WMP29E	RMB18	5.0 m	0.5 mAHD	12.5 mbTOC	[<0.5 m; <0.5 m] ***< 5.0 m***
WMP30A	-	15.7 m[#]	-0.2 mAHD	30.9 mbTOC[~]	[61.0 m; 71.2 m] **To Dry**
WMP30B	-	42.1 m[#]	-26.3 mAHD	56.9 mbTOC[~]	[61.2 m; 71.8 m] **To Dry**
WMP30C	-	**12.6 m** [Y3] **27.9 m** [75%Max]	5.6 mAHD / -9.7 mAHD	24.9 mbTOC / 40.2 mbTOC	[**12.6 m**; **37.1 m**]

mbTOC = metres below top of casing (or stick-up).

* Estimated from steady state model calibration target.

^ Approximately 75% of maximum predicted drawdown where greater than 2.0 m, or equal to the total drilled depth where drawdown extends to a greater depth. Where the predicted drawdown after 3 years is less than 75% of the maximum predicted drawdown, an interim value is also proposed.

[~] Adjusted to be total drilled depth + casing height (stick-up).

[#] Dark blue shading: Interim only, until dry.

Light blue shading: Default triggers for unconsolidated (2 m) and consolidated (5 m) aquifers.

A preliminary groundwater level drawdown trigger of 5 m is proposed for Landholder Bore BH28, which is approximately 75% of the maximum predicted drawdown at the groundwater bore (6.8 mbgl). With the exception of BH28, groundwater level triggers for other private landholder bores within 10 km of the CQC Project would also be set at the default 2 m for unconsolidated aquifers.

10.1.11 Groundwater Quality Triggers

Preliminary groundwater quality triggers have been developed based on the updated statistical datasets provided by Orange Environmental Pty Ltd (2020)[xxii]. These datasets include groundwater quality sampling events up to March 2020 and would continue to be augmented as additional baseline data is acquired by CQCPL in advance of open cut mining operations.

The preliminary groundwater quality triggers developed for select groundwater monitoring bores (noting some bores were predominantly dry during the sampling events) are presented in **Tables 10-2 to 10-5**, cognisant of the contemporary EVs and WQOs described in **Section 6.2**, with default and/or applicable guideline values for contemporary EPP Zones presented separately in **Section 10.10 (Table 10-9)**.

Table 10-2
Preliminary Groundwater Quality Triggers for Investigation – Quaternary Alluvium^

Bore ID	Groundwater Quality Triggers [20th%ile pH] & [80th%ile All Other]				Dissolved Metals [mg/L] [80th%ile]								TN [mg/L] [80th %ile]
	pH	Alkalinity [mg/L]	Salinity										
			EC [µS/cm]	TDS [mg/L]	Al	As	Fe	Mn	Mo	Se	V	Zn	
Quaternary Holocene Estuarine Alluvium													
WMP29A (3)	7.0-7.5	446	-	5,612	-	0.006	-	-	-	-	-	0.025	-
Quaternary Alluvium													
WMP05 (8)	7.1-7.5	666	2,886	1,800	0.234	0.006	0.332	0.392	0.003	0.01	0.012	0.026	3.8
BH01X (8)	6.5-7.1	383	1,294	660	0.01	0.017	4.21	0.797	0.001	0.01	0.01	0.012	48.9
BH16 (8)	6.4-6.9	196	1,054	657	0.01	0.004	0.244	0.924	0.001	0.01	0.01	0.015	0.6
Preliminary Draft (Derived) Guideline Values													
AZ6 (3) [Draft]	6.9-7.3	476	6,687	3,622	0.056	0.007	1.10	0.527	0.002	0.01	0.01	0.017	24.1
AZ6 (8) [Draft]	6.7-7.2	415	1,745	1,039	0.085	0.009	1.60	0.704	0.002	0.01	0.01	0.018	17.8
EPP 2014 (8) [Bison Shallow]	6.6-7.1	423	5,659	3,799	0.067	0.007	1.26	0.625	0.002	0.01	0.012	0.014	14.6

Source: After Orange Environmental Pty Ltd Database (2020).

^ Indicative only. Default and/or applicable guideline values for contemporary EPP Zones should apply in the interim where greater than individual triggers and are presented separately in **Section 10.10**.

(3) Equal to or more than 3 x independent sampling events.

(8) Equal to or more than 8 x independent sampling events, only including sites with 8 or more independent sampling events.

Light blue shaded cells = Existing baseline datasets greater than derived Guideline Value for Draft AZ6 (8).

It is important to note that when comparisons are made with the preliminary draft (derived) guideline values presented in the tables, the 80th%ile values based on existing baseline datasets at a number of groundwater monitoring locations exceed the applicable values (those shaded light blue are greater than dark blue). Thus, in the interim, CQCPL would likely need to demonstrate that when groundwater quality results exceed the triggers during operations that the results, for example, are comparable with and/or within recorded background data ranges.

Table 10-3
Preliminary Groundwater Quality Triggers for Investigation – Quaternary Pleistocene Alluvium^

Bore ID	Groundwater Quality Triggers [20th%ile pH] & [80th%ile All Other]				Dissolved Metals [mg/L] [80th%ile]								TN [mg/L] [80th %ile]
	pH	Alkalinity [mg/L]	Salinity EC [µS/cm]	Salinity TDS [mg/L]	Al	As	Fe	Mn	Mo	Se	V	Zn	
Quaternary Alluvium [Lower] (e.g. Qa, Qpa) / Regolith													
WMP02 (8)	6.5-6.9	447	17,400	12,080	0.014	0.002	0.05	0.388	0.002	0.01	0.01	0.004	4.9
WMP04 (8)	7.4-8.2	540	22,120	14,880	0.02	0.004	0.05	0.066	0.045	0.01	0.01	0.005	4.6
WMP08 (8)	6.7-7.0	723	27,760	19,780	0.01	0.005	0.06	1.31	0.003	0.01	0.01	0.024	1.5
WMP09 (8)	6.6-6.9	802	22,180	15,300	0.01	0.002	0.05	0.639	0.001	0.01	0.01	0.03	0.72
WMP12 (3)	6.9-8.6	528	8,244	5,680	0.12	0.005	0.09	0.167	0.008	0.01	0.01	0.01	32.1
WMP15 (8)	6.8-7.4	491	4,922	2,616	0.37	0.002	0.87	0.129	0.002	0.01	0.01	0.056	0.9
WMP25 (3)	6.1-6.7	46	807	612	-	0.002	-	-	-	-	-	0.029	-
WMP26 (3)	6.7-6.9	911	49,700	37,600	-	0.005	-	-	-	-	-	0.086	-
Preliminary Draft (Derived) Guideline Values													
CZ2 (3) [Draft]	6.7-7.3	512	17,018	12,086	0.095	0.003	0.20	0.387	0.010	0.01	0.01	0.031	6.89
CZ2 (8) [Draft]	6.8-7.3	601	18,876	12,931	0.086	0.003	0.22	0.506	0.011	0.01	0.01	0.024	2.52
EPP 2014 (8) [Bison Shallow]	6.6-7.1	423	5,659	3,799	0.067	0.007	1.26	0.625	0.002	0.01	0.012	0.014	14.6
EPP 2014 (8) [Styx Shallow]	6.5-6.9	624	19,907	15,248	0.131	0.007	1.78	1.512	0.003	0.03	0.03	0.034	2.19
EPP 2014 (8) [Uplands Shallow]	6.9-7.3	839	22,690	15,440	0.020	0.003	0.057	0.632	0.013	0.01	0.01	0.019	2.47

Source: After Orange Environmental Pty Ltd Database (2020).

^ Indicative only. Default and/or applicable guideline values for contemporary EPP Zones should apply in the interim where greater than individual triggers and are presented separately in **Section 10.10**.

(3) Equal to or more than 3 x independent sampling events.

(8) Equal to or more than 8 x independent sampling events, only including sites with 8 or more independent sampling events.

Light blue shaded cells = Existing baseline datasets greater than derived Guideline Value for Draft CZ2 (8).

Table 10-4
Preliminary Groundwater Quality Triggers for Investigation – Styx Coal Measures^

Bore ID	Groundwater Quality Triggers [20th%ile pH] & [80th%ile All Other]				Dissolved Metals [mg/L] [80th%ile]								TN [mg/L] [80th %ile]
	pH	Alkalinity [mg/L]	Salinity										
			EC [µS/cm]	TDS [mg/L]	Al	As	Fe	Mn	Mo	Se	V	Zn	
Styx Coal Measures - Overburden (and Quaternary Alluvium [Lower]) / Weathered Regolith													
WMP04D (8)	6.8-7.1	686	26,360	17,200	0.012	0.001	0.05	0.093	0.002	0.01	0.01	0.058	1.44
WMP10 (8)	6.9-7.2	1,290	18,700	11,800	0.02	0.002	0.076	0.514	0.002	0.01	0.01	0.01	3.06
WMP13 (8)	6.2-6.5	524	49,000	39,740	0.05	0.005	0.904	1.788	0.005	0.05	0.05	0.038	0.96
WMP21D (3)	6.7-6.8	894	41,400	31,160	-	0.011	-	-	-	-	-	0.075	-
Styx Coal Measures - Overburden / Coal Seams and Interburden / Coal Seams													
WMP11 (8)	6.5-6.9	510	32,120	24,020	0.05	0.003	3.086	1.936	0.003	0.05	0.05	0.081	1.76
WMP11D (8)	6.5-6.9	541	31,600	23,300	0.01	0.011	2.902	0.386	0.004	0.05	0.05	0.085	3.44
WMP17D (3)	6.8-7.1	526	40,480	28,160	-	0.005	-	-	-	-	-	0.025	-
WMP18D (3)	6.8-7.3	908	31,400	22,240	-	0.005	-	-	-	-	-	0.045	-
WMP22A (3)	6.8-6.9	937	24,520	16,320	0.01	0.004	1.618	0.641	0.005	0.01	0.01	0.022	1.7
WMP22B (3)	7.2-7.5	829	34,580	23,460	0.05	0.005	0.05	0.274	0.008	0.05	0.05	0.025	6.74
WMP23A*(3)	12.1-12.6	3,120*	24,938	10,680	-	0.002	-	-	-	-	-	0.324	-
WMP24 (3)	7.1-7.3	1,001	-	14,620	-	0.001	-	-	-	-	-	0.006	-
WMP28 (3)	6.9-6.9	557	-	4,004	-	0.004	-	-	-	-	-	0.025	-
WMP29C (3)	11.4-11.9	336	-	12,000	-	0.006	-	-	-	-	-	0.014	-
WMP29D (3)	10.0-11.1	121	-	13,520	-	0.003	-	-	-	-	-	0.224	-
Styx Coal Measures – Underburden (and Quaternary Alluvium [Lower]) / Weathered Regolith													
WMP06 (8)	6.5-6.8	858	5,800	3,388	0.012	0.018	3.55	2.62	0.006	0.01	0.01	0.009	4.7
WMP08D (8)	7.3-7.6	279	14,800	8.780	0.03	0.004	0.36	0.324	0.001	0.01	0.01	0.029	1.12
Preliminary Draft (Derived) Guideline Values													
GZ11 (3) [Draft]	7.5-7.9	793	26,706	17,630	0.015	0.005	1.67	1.193	0.003	0.03	0.03	0.057	2.59
GZ11 (8) [Draft]	6.7-7.0	670	25,483	18,318	0.017	0.006	2.16	1.094	0.003	0.03	0.03	0.044	2.35
EPP 2014 (8) [Bison Moderate]	6.5-6.9	526	31,860	23,660	-	0.007	2.99	1.16	0.004	0.05	0.05	0.083	2.6
EPP 2014 (8) [Styx Shallow]	6.5-6.9	624	19,907	15,248	0.131	0.007	1.78	1.512	0.003	0.03	0.03	0.034	2.19
EPP 2014 (8) [Uplands Shallow]	6.9-7.3	839	22,690	15,440	0.020	0.003	0.057	0.632	0.013	0.01	0.01	0.019	2.47

Source: After Orange Environmental Pty Ltd Database (2020).

^ Indicative only. Default and/or applicable guideline values for contemporary EPP Zones should apply in the interim where greater than individual triggers and are presented separately in **Section 10.10**.

(3) Equal to or more than 3 x independent sampling events.

(8) Equal to or more than 8 x independent sampling events, only including sites with 8 or more independent sampling events.

Light blue shaded cells = Existing baseline datasets greater than derived Guideline Value for Draft GZ11 (8).

*Alkaline pH considered to be due to deep borehole construction (i.e. residual unset cement).

Table 10-5
Preliminary Groundwater Quality Triggers for Investigation – Permian Measures^

Bore ID	Groundwater Quality Triggers [20th%ile pH] & [80th%ile All Other]				Dissolved Metals [mg/L] [80th%ile]								TN [mg/L] [80th %ile]
	pH	Alkalinity [mg/L]	Salinity EC [µS/cm]	Salinity TDS [mg/L]	Al	As	Fe	Mn	Mo	Se	V	Zn	
Permian Measures - Back Creek Group (and Styx Coal Measures - Underburden)													
WMP29E*(3)	12.1 - 12.4	3,104*	-	5,848	-	0.005	-	-	-	-	-	0.042	-
WMP22C (3)	9.9-10.4	273	4,796	2,876	-	0.002	-	-	-	-	-	0.013	-
WMP16D (3)	7.4-7.5	435	8,622	5,076	-	0.001	-	-	-	-	-	0.146	-
WMP19D (3)	6.6-6.9	532	1,978	1,260	-	0.006	-	-	-	-	-	0.049	-
WMP20D (3)	7.0-7.3	787	1,992	1,280	-	0.006	-	-	-	-	-	0.107	-
Permian Measures – Carmila Beds (and/or Back Creek Group)													
WMP23B*(3)	12.2 - 12.6	2,564*	16,906	6,900	-	0.003	-	-	-	-	-	0.035	-
Preliminary Draft (Derived) Guideline Values													
FR10 (3) [Draft]	7.1-7.3	884	4,658	3,426	0.01	0.004	0.867	0.834	0.005	0.01	0.01	0.053	2.0
EPP 2014 (8) [Bison Shallow]	6.6-7.1	423	5,659	3,799	0.067	0.007	1.26	0.625	0.002	0.01	0.012	0.014	14.6
EPP 2014 (3) [Styx Moderate]	6.8-7.3	527	7,677	4,941	0.01	0.004	1.99	1.807	0.005	0.01	0.01	0.063	1.13
EPP 2014 (8) [Uplands Moderate]	7.0-7.3	483	20,580	12,990	0.021	0.003	0.205	0.209	0.002	0.01	0.01	0.044	1.28

Source: After Orange Environmental Pty Ltd Database (2020).

^ Indicative only. Default and/or applicable guideline values for contemporary EPP Zones should apply in the interim where greater than individual triggers and are presented separately in **Section 10.10**.

(3) Equal to or more than 3 x independent sampling events.

(8) Equal to or more than 8 x independent sampling events, only including sites with 8 or more independent sampling events.

Light blue shaded cells = Existing baseline datasets greater than derived Guideline Value for Draft FR10 (3).

*Alkaline pH considered to be due to deep borehole construction (i.e. residual unset cement).

10.2 WATER MANAGEMENT PLAN

A Water Management Plan would be prepared for the CQC Project, guided by the assessment outcomes in WRM Water & Environment (2020) and include, but may not necessarily be limited to:

- a description of the regional and local catchments and drainage characteristics (**Section 3.0**);
- relevant EVs and WQOs of the regional and local drainage receiving waters (**Section 6.2**), subject to any future updates should relevant draft EVs be finalised, and relevant trigger and investigation values, and how these compare with relevant groundwater triggers (in particular for Quaternary Alluvium) (**Table 10-2**);
- details of on-site operating activities (for the period of the plan), including potential water contaminant sources (including sediments);
- a description of the surface water management system, including management objectives and principles;
- the site water balance model (based on the predicted groundwater model pit inflows), forecast estimates and performance over the life of the mine, including advance dewatering for water supply if required;
- an overview of the surface water monitoring network and complementary groundwater monitoring network (**Section 10.1**), sediment monitoring and reporting (including WaTERS database reporting); and
- integration with emergency and/or contingency planning where relevant to water management.

Detailed Erosion and Sediment Control Plan(s) would be developed as a separate component to the Water Management Plan and concept is outlined in **Section 10.2.1**.

Revisions to the Water Management Plan would be undertaken as required to reflect updates to future groundwater model validation exercises (e.g. actual/forecast pit inflows and/or advance dewatering for water supply which may affect site water balance and performance over the life of the mine).

10.2.1 Erosion and Sediment Control Plan (Draft)

A draft Conceptual Erosion and Sediment Control Plan (ESCP) has been developed by Engeny Water Management (2020), cognisant of the contemporary requirements prescribed for Certified Professionals in Erosion and Sediment Control and Registered Professional Engineers of Queensland. The final detailed ESCP(s) would describe:

- the catchment areas and relevant soil classifications (including sodic dispersive soils);
- the erosion and sediment control measures to minimise the release of sediment to receiving waters including proposed design criteria for erosion and sediment control structures;
- the locations and types of erosion and sediment control structures; and
- audit schedule for maintenance of erosion and sediment control structures.

Changes in local catchment areas to the downstream reaches of Tooloombah Creek (Reach 2) and Deep Creek (Reach 1), particularly where up-catchment diversions are installed as a result of erosion and sediment control measures, would be considered for future groundwater model validation.

10.2.2 Trigger Action Response Plan(s)

Trigger Action Response Plan(s) would be developed as part of the Water Management Plan and final detailed ESCP(s) to integrate with surface water (flow and quality) monitoring programs, erosion and sediment monitoring, stream health and vegetation monitoring developed separately by others.

In particular, should recorded pit groundwater inflows be substantially greater than those predicted in **Section 8.4 (Table 8-3)**, when compared to the quantitative UA estimates (**Table 8-8**), appropriate review and response mechanisms would be commenced.

Similarly, should changes in local catchment areas to the downstream reaches of Tooloombah Creek (Reach 2) and Deep Creek (Reach 1), particularly where up-catchment diversions are installed for erosion and sediment control and result in measurable changes in local flow regime, appropriate review and response mechanisms would be commenced (i.e. for future groundwater model stage validation).

10.3 MINERAL WASTE MANAGEMENT PLAN

Waste rock and coal reject (including coarse rejects and filter press tailings [dewatered fine rejects]) emplacement activities would be conducted in accordance with a Mineral Waste Management Plan, guided by the assessment outcomes presented in RGS (2020). Dewatered fine rejects would be disposed of in-pit as the open cut mining areas are developed and blended with overburden waste rock (bulk spoil).

The Mineral Waste Management Plan would include, but may not necessarily be limited to:

- characterisation of waste rock and coal rejects (**Section 4.5**) and production quantities and volumes (**Section 8.3.4**);
- identification of appropriate performance measures (e.g. to prevent or minimise the migration of pollutants beyond the excavated pit extent or seepage from out-of-pit emplacements);
- reject disposal management, including material handling methodologies, scheduling and water management;
- rehabilitation strategies both in the short-term and long-term, with consideration of backfilling activities, final landforms, flood interactions (if any) and post-mine closure equilibrium groundwater levels (**Section 8.9**); and
- ongoing mine water (e.g. collected from dewatered fine rejects prior to rehabilitation) and groundwater monitoring (**Section 10.3.1**), assessment, review (**Section 10.7**) and improvement of performance.

10.3.1 Groundwater (Seepage) Monitoring

Groundwater (seepage) monitoring downgradient of dewatered fine reject disposal areas would be undertaken by a number of the existing groundwater monitoring network bores (e.g. WMP04, WMP04D, WMP18, WMP18D, WMP21, WMP21D and WMP26) which if required could be augmented at a refined scale with additional shallow (near surface) piezometers. Any additional piezometers should be installed within the first three (3) years of the operation to ensure baseline data is able to be collected in advance of the longer-term reject disposal in designated areas.

The groundwater (seepage) monitoring bores would monitor for potential seepage (enhanced by rainfall infiltration) from elevated out-of-pit waste rock emplacements toward the Cenozoic sediments and regolith. However, as demonstrated in **Attachments 14 and 15**, it is expected that the advancing pit (once developed) would remain as a temporal and localised sink to which surrounding groundwaters would flow toward.

The initial seepage monitoring program for additional piezometers (if required) would include monthly groundwater level and quarterly groundwater quality sampling. This data would be used in conjunction with the existing groundwater monitoring network to determine relevant baseline conditions and detect any unexpected influence due to seepage enhanced by rainfall infiltration.

10.4 GROUNDWATER LICENSING

As described in **Section 2.1.2**, a Water Plan has not been established under the *Water Act 2000* for the Styx Surface Water Basin (**Figure 2-1**). If a future catchment-specific Water Plan is developed, the CQC Project would be required to consider the relevant licensing requirements at that time[39].

When and/or if required for the purposes of groundwater take (**Sections 8.4 to 8.7**), an associated water licence would be sought under the *Water Act 2000* in accordance with Section 1250C(1) to authorise the:

> *'…taking of or interference with underground water in the area of a mining tenure if the taking or interference happens during the course of, or results from, the carrying out of an authorised activity for the tenure.'*

As outlined in **Table 2-1**, **this Report** has in any case considered the minimum reporting requirements for groundwater impact assessments outlined within the *Guideline Requirements for site-specific and amendment applications – underground water rights* relating to Section 126A of the EP Act.

10.5 GROUNDWATER DEPENDENT ECOSYSTEM MANAGEMENT AND MONITORING PLAN (GDEMMP)

A draft Groundwater Dependent Ecosystem Management and Monitoring Plan (GDEMMP), including a GDE and wetland monitoring program has been developed by Eco Logical Australia Pty Ltd (2020b), cognisant of the *EIS Information Guideline – Groundwater Dependent Ecosystems* (DEHP, 2016) and IESC *Information Guidelines Explanatory Note: Assessing Groundwater-Dependent Ecosystems* (dated 8 March 2019) and describes:

- processes for numerical groundwater model review and validation (**Section 10.9**);
- the groundwater (level and pressure) monitoring network in all hydrogeological units (**Sections 5.0 and 10.1**) to monitor drawdown impacts (**Section 10.1.10**) and flow directions (**Figures 8-6[a-f]**);
- monitoring of aquifers identified as potentially being impacted from groundwater drawdown (**Sections 8.5, 10.1.7, 10.1.8 and 10.1.9**); and
- identification of groundwater drawdown level thresholds for monitoring impacts on GDEs (**Sections 8.7.2, 8.7.3, 8.7.4, 8.7.5, 10.1.4, 10.1.5, 10.1.6, 10.5.1 and 10.5.2**).

The GDEMMP is prepared to identify (based on the conceptualisation [**Section 6.3**] and numerical model predictions [**Section 8.0**]) and refine the potential impacts described in **Section 9.0** to ensure all potential consequential effects from mine dewatering (**Sections 8.3.1 and 8.4**), mine water storage/management (WRM Water & Environment, 2020) and mineral waste management (RGS, 2020) (**Section 10.3**) are identified, mitigated and monitored.

Required offsets for GDEs and species considering any significant residual impacts (**Section 11.2**) would also be identified in the GDEMMP.

10.5.1 Groundwater Dependent Ecosystem and Wetland Monitoring Program

The GDE and wetland monitoring program would be detailed in the GDEMMP and effectively be a subset of the proposed groundwater monitoring program components (**Sections 10.1.4 to 10.1.6**) with additional monitoring, as required.

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[39] Including the date the EA application was first made.

10.5.2 Trigger Action Response Plan(s)

Trigger Action Response Plan(s) would be developed and included in the GDEMMP generally consistent with the groundwater level and quality triggers described in **Sections 10.1.10 and 10.1.11** (e.g. WMP04, WMP05, WMP06, WMP25 and WMP27), and integration with surface water (flow and quality) monitoring programs (WRM Water & Environment, 2020), erosion and sediment monitoring (Engeny Water Management, 2020), stream health and vegetation monitoring developed separately by others (Eco Logical Australia Pty Ltd, 2020a).

10.6 RECEIVING ENVIRONMENT MONITORING PROGRAM (REMP)

A draft Receiving Environment Monitoring Program (REMP) has been developed by Eco Logical Australia Pty Ltd (2020c) cognisant of the *Receiving Environment Monitoring Program Guideline – For Use with Environmentally Relevant Activities under the Environmental Protection Act 1994* (DSITIA, 2015).

The REMP would describe the:

- characteristics of all potential mine-related water impacts (flow and quality);
- local receiving waters, including consideration of rainfall, existing land use, streamflow and water quality, existing bank stability and erosion, stream sediment and geomorphology, aquatic habitat, vegetation, macroinvertebrates and fish species;
- potential risks to EVs of the receiving waters and WQOs (including relevant sediment quality guidelines);
- the receiving environment monitoring program including locations, frequencies and key performance indicators (including trigger action response plans [TARPs]), and specifically a program for estimating changes in sediment load and particle size distribution to assess the potential impacts from stream bed/bank erosion and sediment mobilisation; and
- performance reporting mechanisms and review schedule.

The results of sediment monitoring would be integrated with the Water Management Plan and Erosion and Sediment Control Plan (Engeny Water Management, 2020) (**Section 10.2**) and considered in future revisions. Record-keeping of controlled water releases would be important to inform future groundwater model validation.

10.6.1 Groundwater Monitoring

If required, the groundwater monitoring components of the REMP would be a sub-set of those outlined in **Section 10.3.1**. However, recognising the requirements of the relevant guideline, land uses and other point source releases would be described including upstream and downstream of the activity within the REMP area that may: (i) influence existing water quality and/or hydrology, and/or (ii) contribute to potential cumulative impacts. Additional groundwater monitoring if required (e.g. for the management of sub-surface drainage at temporary out-of-pit placement of rejects) would be outlined in the REMP (Eco Logical Australia Pty Ltd, 2020c).

10.6.2 Surface Water Monitoring

The REMP surface water monitoring would be guided by the assessment outcomes in WRM Water & Environment (2020) and Eco Logical Australia Pty Ltd (2020c).

The REMP surface water monitoring data collected would importantly be used to inform future groundwater model validation (i.e. river stage and baseflow), particularly if controlled surface water flow releases were to be undertaken which may influence the existing water quality and/or hydrology (i.e. become an additional recharge source).

10.6.3 Trigger Action Response Plan(s)

Trigger Action Response Plans would be outlined in Eco Logical Australia Pty Ltd (2020c). Should controlled water releases occur during a reporting period, record-keeping of additional water volumes would be important to inform future groundwater model validation.

10.7 ANNUAL MONITORING REVIEW AND REPORTING

Consistent with contemporary reporting requirements for an EA, an annual monitoring report should be prepared for the CQC Project to report the relevant groundwater datasets to the Qld Government for the annual return period. Similarly, any details of reviews of the numerical groundwater model predictions, or updates to the numerical groundwater model (e.g. re-calibration, additional sensitivity analysis or revised forward predictions) (**Section 10.9**) should be reported.

Relevant water monitoring data and reports would be submitted to the Qld Government's Water Tracking and Electronic Report System (WaTERS) database, as and when required. The water monitoring data and reports would be used to inform future groundwater model validation.

10.8 MITIGATION / MAKE GOOD MEASURES

10.8.1 Private Landholder Bores

As discussed in **Section 8.7.1**, only one private landholder bore (BH28 [McCartney {97864}]) is predicted to be impacted beyond the 5 m bore trigger threshold defined in the *Water Act 2000* for consolidated aquifers.

A baseline assessment cognisant of the Qld *Guideline Baseline Assessments* (DES, 2017) would therefore be conducted as a component of the proposed groundwater monitoring program (as described in **Section 10.1.2**) to determine the appropriate mitigation / make good measures, and ongoing monitoring requirements.

However, based on the details in **Table 8-4**, if the baseline assessment was to confirm the screen interval is at substantial depth (e.g. 32-54 mbgl) and the standing water level was well above the screen (and submersible pump, if in use), make good measures may not necessarily be required as the maximum predicted drawdown is only 6.8 m which may not result in a discernible change in groundwater yield at the bore.

It is recommended that periodic (e.g. seasonal/quarterly, or less frequently if otherwise agreed) water level monitoring also be conducted during the operational life of the CQC Project at BH28 and to confirm / verify the groundwater model predictions toward the north (e.g. BH24 and BH01X or BH16) as discussed in **Section 10.1.2**.

10.8.2 Supplementary Water Inputs

No supplementary water inputs are proposed by CQCPL for the CQC Project, therefore do not require consideration for future groundwater model validation (i.e. as a potential future input to streamflow). However, it is noted that controlled water releases may occur as outlined in WRM Water & Environment Pty Ltd (2020).

Record-keeping of such additional water volumes/inputs would be important to inform future groundwater model validation and is relevantly noted as a component of the REMP.

10.9 NUMERICAL GROUNDWATER MODEL REVIEW

The numerical groundwater model would be subject to review at least every three (3) years from the commencement of open cut mining, in line with the indicative review timeframes prescribed for UWIRs in Qld. Where additional validation datasets become available and the outcomes of a review were to recommend, the numerical groundwater model may, from time-to-time, be re-calibrated to improve the model performance. At such times, other potential adjustments and/or improvements to the numerical groundwater model could be undertaken, including those identified during the peer review.

Notably, model review validation exercises, and sensitivity analysis have already been carried out and are described in **Sections 7.8 and 8.11.6**.

As described in **Section 10.5**, the GDEMMP would also recognise the future processes for numerical groundwater model review and validation, and more specifically review of applied boundary and groundwater recharge conditions (as outlined in **Sections 7.5, 7.7.2 and 7.8.1**). Applied streambed conductivity (i.e. 0.01 m/day) (**Section 8.11.6**) and spatially variable aquifer parameters (**Attachment 11**) for the groundwater model layers could also be considered further during future model validation processes.

10.10 DRAFT ENVIRONMENTAL AUTHORITY CONDITIONS

The draft EA conditions below have been developed based on a review of the *Guideline Mining: Model Mining Conditions* (ESR/2016/1936), as well as existing coal mining operations and contemporary Qld mining project approvals in the Bowen Basin to help expedite the process of developing appropriate conditions for an EA for a mining project in consultation with the DES. The trigger values presented draw upon the analysis and summaries for the proposed groundwater level and quality triggers derived in **Sections 10.1.10 and 10.1.11**.

For consistency, reference is made to Schedule E for groundwater-related conditions (and supporting Tables E1 and E2). The draft EA conditions relating to groundwater are provided in **Tables 10-6, 10-7, 10-8 and 10-9**. Figure E1 referred to in draft Condition E6 relates to **Figures 5-1[a & b]**.

Importantly, it is recognised that the groundwater monitoring program would be staged in a manner to allow for the detection of impacts to groundwater levels and quality by authorised mining activities but, at the same time during the early stages of the CQC Project would continue to augment baseline datasets to refine and establish triggers later in the life of the mine. Thus, the reference and compliance categories applied in **Table 10-7** would change over time.

Table 10-6
Draft Environmental Authority Conditions – Schedule E: Groundwater

Condition Number	Condition
E1	The holder of this environmental authority must not release contaminants to groundwater.
E2	Groundwater monitoring and analysis must be performed by an appropriately qualified person.
E3	The holder of this environmental authority must develop and implement a **groundwater monitoring program** prior to commencement of relevant mining activities, unless otherwise agreed in writing with the administering authority.
E4	The **groundwater monitoring program** must be developed by a suitably qualified person and submitted to the administering authority for review and comment, including timeframes for staged installation and commissioning for the proposed supplementary groundwater monitoring locations. The groundwater monitoring program must: (1) identify potential sources of contamination to groundwater; (2) ensure that all potential groundwater impacts due to the activity are identified, monitored and mitigated; (3) document sampling and monitoring methodology; (4) ensure that adequate groundwater monitoring and data analysis is undertaken to achieve the following objectives: a) detect any impacts to groundwater levels due to the activity that are part of the authorised mining activities; b) detect any impacts to groundwater quality due to the activity that are part of the authorised mining activities; and c) determine trends in groundwater levels and groundwater quality; (5) include an appropriate quality assurance program; (6) include a conceptual groundwater flow model; and (7) include a review process to continually improve the groundwater monitoring program.
E5	A suitably qualified person (or persons) must review the **groundwater monitoring program** on an annual basis, including all relevant groundwater data collected during the review period. The review must: (1) be in a report format and submitted to the administering authority with each annual return; (2) include a description of any supplementary groundwater monitoring locations constructed and commissioned, or any existing groundwater monitoring locations decommissioned, during the review period; (3) present the groundwater level and groundwater quality data for the review period, including an assessment of trends, including seasonal variation, private landholder users and/or authorised mining activities; and (4) assess the suitability of the groundwater monitoring network, both spatially and temporally, to satisfy the requirements for all groundwater aquifers potentially impacted by the authorised mining activities to be monitored for the review period.
E6	**Groundwater levels** Groundwater levels affected by the mining activities must be monitored at the locations and frequencies defined in **Table E1 – Groundwater Monitoring Locations and Frequency** as shown on **Figure E1 – Current and Proposed Groundwater Monitoring Locations.**
E7	Any proposed supplementary groundwater monitoring locations beyond those listed in **Table E1 – Groundwater Monitoring Locations and Frequency** must be installed and commissioned in accordance with **Condition E4** within three (3) years of the commencement of the development, unless otherwise agreed in writing with the administering authority.
E8	Subject to the groundwater monitoring requirements of **Condition E6**, if the groundwater investigation trigger levels defined in **Table E2 – Groundwater Investigation Trigger Levels** are exceeded then the environmental authority holder must complete an investigation into the potential for environmental harm and notify the administering authority within twenty-eight (28) days of receiving the analysis results to determine if the fluctuations are a results of: (a) mining activities; (b) pumping from licensed landholder bores; or (c) seasonal variation.
E9	If the results of the investigation undertaken in accordance with **Condition E8** identify that the groundwater level changes are a direct result of mining activities, the holder of the environmental authority must notify the administering authority and provide a copy of a report detailing the findings and outcomes of the investigation within seven (7) days of completing the investigation.

Table 10-6 (Cont.)
Draft Environmental Authority Conditions – Schedule E: Groundwater

Condition Number	Condition
E10	**Groundwater quality** Groundwater quality must be monitored at the locations and frequencies listed in **Table E1 – Groundwater Monitoring Locations and Frequency** and **Figure E1 – Current and Proposed Groundwater Monitoring Locations** for the water quality parameters identified in **Table E2 – Groundwater Quality Investigation Trigger Levels**.
E11	Subject to groundwater monitoring requirements of **Condition E10**, if the groundwater quality investigation trigger levels defined in **Table E3: Groundwater Quality Investigation Trigger Levels** are exceeded then the environmental authority holder must complete an investigation into the potential for environmental harm, including comparisons with baseline concentration ranges, and notify the administering authority within twenty-eight (28) days of receiving the analysis results.
E12	The construction, maintenance and management of groundwater bores (including groundwater monitoring bores) must be undertaken in a manner that prevents or minimises impacts to the environment and ensures the integrity of the bores to obtain accurate monitoring.

Table 10-7
Table E1 - Draft Groundwater Monitoring Locations and Frequency

Monitoring Point	Location (X, Y)		Elevation (Z)		Screen Depth (mbgl)	Target Aquifer	Monitoring Frequency*
	Latitude	Longitude	Ground Surface (mAHD)	Stick-Up (cm)			
RMB01 (WMP13)	-22.621682	149.652024	18.4	90	14.1-21.1	Styx Overburden [Kx] / Weathered Regolith / Qpa [~GZ11]	Quarterly
RMB02 (WMP11)	-22.642371	149.667884	18.8	110	18-24	Styx Overburden [Kx] [~GZ11]	Quarterly
RMB03 (WMP11D)	-22.642252	149.667950	18.8	110	30-36	Styx Overburden [Kx] [~GZ11]	Quarterly
RMB04 (WMP17)	-22.735128	149.682050	42.8	75	9-12	Pleistocene Alluvial (Qpa) / Regolith [~CZ2]	Quarterly
RMB05 (WMP17D)	-22.735326	149.682103	42.8	55	21-24	Styx Overburden [Kx] [~GZ11]	Quarterly
RMB06 (WMP08)	-22.754042	149.669504	43.5	100	10-16	Pleistocene Alluvial (Qpa) / Regolith [~CZ2]	Quarterly
RMB07 (WMP08D)	-22.754079	149.669466	43.5	100	24-36	Styx Underburden [Kx] [~GZ11]	Quarterly
RMB08 (WMP19)	-22.714833	149.616881	41.0	65	13.1-16.1	Regolith / Back Creek Group [Pb] [~FZ10]	Quarterly
RMB09 (WMP19D)	-22.714690	149.616810	41.0	60	24.9-27.9	Back Creek Group [Pb] [~FZ10]	Quarterly
RMB10 (WMP16)	-22.636361	149.606853	41.9	65	25.5-31.5	Back Creek Group [Pb] [~FZ10]	Quarterly

Table 10-7 (Continued)
Table E1 - Draft Groundwater Monitoring Locations and Frequency

Monitoring Point	Location (X, Y)		Elevation (Z)		Screen Depth (mbgl)	Target Aquifer	Monitoring Frequency*
	Latitude	Longitude	Ground Surface (mAHD)	Stick-Up (cm)			
RMB11 (WMP16D)	-22.636426	149.606786	41.8	75	35.7-41.7	Back Creek Group [Pb] [~FZ10]	Quarterly
RMB12 (WMP20)	-22.675143	149.610708	43.0	55	14.5-20.5	Regolith / Back Creek Group [Pb] [~FZ10]	Quarterly
RMB13 (WMP20D)	-22.675161	149.610660	43.0	50	24-30	Back Creek Group [Pb] [~FZ10]	Quarterly
RMB14 (WMP29A)	-22.608771	149.639079	12.0 [**11.3**]*	100	6.5-12.5	Alluvial (Qa/Qhe) [~AZ6]	**Continuous Datalogger** / Quarterly
RMB15 (WMP29B)	-22.608770	149.639108	12.0	100	16-20	Pleistocene Alluvial (Qpa) / Regolith [~CZ2]	Quarterly
RMB16 (WMP29C)	-22.608686	149.639271	12.0	100	52-58	Styx Overburden [Kx] [~GZ11]	Quarterly
RMB17 (WMP29D)	-22.608750	149.639263	12.0	100	115-121	Styx Overburden [Kx] [~GZ11]	Quarterly
RMB18 (WMP29E)	-22.608660	149.639213	12.0	100	222.5-228.5	Back Creek Group [Pb] [~FZ10]	Quarterly
CMB01 (WMP05)	-22.660106	149.671271	17.2 [**15.5**]*	100	9-12	Alluvial (Qa) [~AZ6]	**Continuous Datalogger** **[Level Only]** / Quarterly
CMB02 (WMP21)	-22.674281	149.669474	23.8	65	6.9-9.9	Alluvial (Qa) [~AZ6]	Quarterly
CMB03 (WMP21D)	-22.674903	149.668990	26.0	55	14-20	Styx Overburden [Kx] [~GZ11]	Quarterly
CMB04 (WMP18)	-22.700529	149.680412	30.5	55	9.2-12.2	Pleistocene Alluvial (Qpa) / Regolith [~CZ2]	Quarterly
CMB05 (WMP18D)	-22.700458	149.680333	30.6	45	18.5-23.5	Styx Overburden [Kx] [~GZ11]	Quarterly
CMB06 (WMP10)	-22.704560	149.685472	29.3	80	13.9-19.9	Styx Overburden [Kx] [~GZ11]	Quarterly
CMB07 (WMP09)	-22.728651	149.662403	37.6	100	7.1-15.1	Pleistocene Alluvial (Qpa) / Regolith [~CZ2]	Quarterly
CMB08 (WMP07)	-22.737226	149.641208	131.0	100	53-65	Styx Underburden [Kx] [~GZ11]	Quarterly
CMB09 (WMP15)	-22.715369	149.645751	43.3	120	9.3-21.3	Regolith / Styx Underburden [Kx] / Back Creek Group [Pb] [~GZ11]	Quarterly
CMB10 (WMP25)	-22.709541	149.636279	44.2	60	10.1-13.1	Pleistocene Alluvial (Qpa) / Regolith [~CZ2]	Quarterly

Table 10-7 (Continued)
Table E1 - Draft Groundwater Monitoring Locations and Frequency

Monitoring Point	Location (X, Y)		Elevation (Z)		Screen Depth (mbgl)	Target Aquifer	Monitoring Frequency*
	Latitude	Longitude	Ground Surface (mAHD)	Stick-Up (cm)			
CMB11 (WMP14)	-22.696779	149.632833	32.9	110	10-19	Regolith / Styx Overburden [Kx] [~GZ11]	Quarterly
CMB12 (WMP06)	-22.692585	149.628249	34.0	70	12-18	Regolith / Styx Underburden [Kx] [~GZ11]	**Continuous Datalogger** / Quarterly
CMB13 (WMP04)	-22.680956	149.655703	28.3	120	12.6-18.6	Pleistocene Alluvial (Qpa) / Regolith [~CZ2]	**Continuous Datalogger** **[Level Only]** / Quarterly
CMB14 (WMP04D)	-22.681020	149.655645	28.3	90	21.9-39.9	Styx Overburden [Kx] / Weathered Regolith / Qpa [~GZ11]	Quarterly
CMB15 (WMP12)	-22.668501	149.659363	26.4	110	11.9-17.9	Pleistocene Alluvial (Qpa) / Regolith [~CZ2]	Quarterly
CMB16 (WMP02)	-22.659413	149.661435	25.0	110	13.4-19.4	Pleistocene Alluvial (Qpa) / Regolith [~CZ2]	Quarterly
CMB17 (WMP22A)	-22.685308	149.647450	29.7	35	27-30	Styx Overburden [Kx] [~GZ11]	Quarterly
CMB18 (WMP22B)	-22.685263	149.647478	29.7	30	50-56	Styx Overburden [Kx] [~GZ11]	Quarterly
CMB19 (WMP22C)	-22.685226	149.647487	29.8	50	200-206	Back Creek Group [Pb] [~FZ10]	Quarterly
CMB20 (WMP23A)	-22.722853	149.664159	36.4	90	48.5-54.5	Styx Overburden [Kx] [~GZ11]	Quarterly
CMB21 (WMP23B)	-22.722783	149.664032	36.4	90	187-193	Back Creek Group [Pb] / Carmila Beds [Pc] [~FZ10]	Quarterly
CMB22 (WMP24)	-22.683492	149.646996	19.4	50	23.4-26.4	Styx Overburden [Kx] [~GZ11]	Quarterly
CMB23 (WMP26)	-22.680702	149.663383	27.6	50	11.5-20.5	Pleistocene Alluvial (Qpa) / Regolith [~CZ2]	Quarterly
CMB24 (WMP27)	-22.695830	149.634012	33.0	85	14.5-20.5	Regolith / Styx Overburden [Kx] [~GZ11]	Quarterly
CMB25 (WMP28)	-22.683402	149.649203	21.9	60	8.9-11.9	Regolith / Styx Overburden [Kx] [~GZ11]	Quarterly
VWP (WMP31)	-22.682770	149.706370	47.0	-	50.0^	Back Creek Group [Pb] [~FZ10]	**Continuous Datalogger** **[Level Only]**
					94.0^	Back Creek Group [Pb] [~FZ10]	**Continuous Datalogger** **[Level Only]**
					103.5^	Back Creek Group [Pb] [~FZ10]	**Continuous Datalogger** **[Level Only]**
					171.0^	Back Creek Group [Pb] [~FZ10]	**Continuous Datalogger** **[Level Only]**

*Monitoring frequency would be subject to ongoing review.

^ Wire Depth.

Table 10-8
Table E2 - Draft Groundwater Level Investigation Trigger Levels

Monitoring Points (Refer Table E1)	Preliminary Groundwater Level (Change) Investigation Trigger Threshold		
	Year 3	Interim	Maximum
WMP05, WMP08, WMP08D, WMP11, WMP11D, WMP13, WMP16, WMP16D, WMP17D, WMP19, WMP19D, WMP20D, WMP29A, WMP29B	>2.0 m	>2.0 m	>2.0 m
WMP29C, WMP29D, WMP29E, WMP31	>5.0 m	>5.0 m	>5.0 m
WMP02, WMP06, WMP07, WMP10, WMP12, WMP14, WMP17, WMP18, WMP18D, WMP20, WMP21, WMP27, WMP28	>2.0 m	Dry	-
WMP04, WMP22A, WMP22B, WMP30A, WMP30B	Dry	Dry	-
WMP21D	2.1 m	Dry	-
WMP26	5.3 m	Dry	-
WMP25	>2.0 m	>2.0 m	2.7 m
WMP09	>2.0 m	2.9 m	3.8 m
WMP15	>2.0 m	5.3 m	7.1 m
WMP23A	>2.0 m	12.0 m	16.0 m
WMP23B	>5.0 m	20.3 m	27.1 m
WMP24	4.5 m	4.5 m	5.3 m
WMP04D	13.4 m	16.2 m	21.6 m
WMP22C	12.4 m	27.6 m	36.7 m
WMP30C	12.6 m	27.9 m	37.1 m

Table 10-9
Table E3 - Draft Groundwater Quality Investigation Trigger Levels

Parameter	Unit	Default Maximum Trigger	Preliminary Trigger Type	Preliminary Groundwater Quality Investigation Trigger Threshold per Draft EPP Zone* / Hydrogeological Unit			
				AZ6 (e.g. Qa)	CZ2 (e.g. Qpa)	GZ11 (e.g. Kx)	FZ10 (e.g. Pb)
pH	pH Units	6.5-8.5	20th-80th%ile	**6.2-8.0**	7.2-**8.1**	7.5-**8.2**	7.5-**8.2**
				6.7-7.2	**6.8**-7.3	**6.7**-7.0	**7.1**-7.3
Electrical Conductivity	µS/cm	-	80th%ile	1,025	9,519	10,670	3,191
				1,745	**18,876**	**25,483**	**4,658**
Total Dissolved Solids	mg/L	35,000 [Seawater]	80th%ile	-	-	-	-
				1,039	**12,931**	**18,318**	**3,426**
Calcium	mg/L	1,000	80th%ile	**68**	99	248	138
				47	**255**	**456**	**156**
Magnesium	mg/L	2,000	80th%ile	22	200	433	128
				36	**452**	**671**	**133**
Sodium	mg/L	6,700	80th%ile	133	1,502	1,965	360
				268	**3,524**	**4,866**	**869**
Potassium	mg/L	-	80th%ile	-	-	-	-
				6	**7**	**8**	**36**
Chloride	mg/L	12,700	80th%ile	201	2,817	4,500	757
				325	**6,398**	**8,971**	**1,327**
Sulphate (SO_4)	mg/L	1,000	80th%ile	47	173	**896**	107
				61	**707**	522	**110**
Carbonate (CO3)	mg/L	-	80th%ile	-	-	-	-
				1	**3**	**1**	**399**
Bicarbonate (HCO_3)	mg/L	-	80th%ile	279	368	**850**	**615**
				415	**600**	669	416
Hydroxide (OH)	mg/L	-	80th%ile	-	-	-	-
				1	**1**	**1**	**1**
Total Alkalinity	mg/L	-	80th%ile	232	448	**705**	620
				415	**601**	670	**884**
Nitrate (NO_3)	mg/L	1.1^{+}	80th%ile	**2.6**	**2.6**	**7.5**	**16.0**
				0.044	0.663	0.076	0.082
Total Nitrogen (TN)	mg/L	-	80th%ile	0.57	0.55	1.6	**3.5**
				17.8	**2.5**	**2.4**	2.0
Aluminium [Dissolved]	mg/L	5^ or 0.055^{+}	80th%ile	-	-	-	-
				0.085	**0.086**	**0.017**	**0.01**
Arsenic [Dissolved]	mg/L	0.5^ or 0.013^{+}	80th%ile	-	-	-	-
				0.009	**0.003**	**0.006**	**0.004**
Barium [Dissolved]	mg/L	-	80th%ile	-	-	-	-
				0.163	**0.223**	**1.308**	**0.083**
Boron [Dissolved]	mg/L	5^ or 0.37^{+}	80th%ile	-	-	-	-
				-	-	-	-
Cadmium [Dissolved]	mg/L	0.01^ or 0.0002^{+}	80th%ile	-	-	-	-
				0.0001	**0.0002**	**0.0003**	**0.0001**
Chromium [Dissolved]	mg/L	1^ or 0.001^{+}	80th%ile	-	-	-	-
				0.002	**0.004**	**0.003**	**0.024**
Copper [Dissolved]	mg/L	1^ or 0.002^{+}	80th%ile	**0.015**	-	**0.025**	**0.050**
				0.003	**0.004**	0.001	0.003

Table 10-9 (Continued)
Table E3 - Draft Groundwater Quality Investigation Trigger Levels

Parameter	Unit	Default Maximum Trigger	Preliminary Trigger Type	Preliminary Groundwater Quality Investigation Trigger Threshold per Draft EPP Zone* / Hydrogeological Unit			
				AZ6$^{\sim}$ (e.g. Qa)	CZ2$^{\sim}$ (e.g. Qpa)	GZ11$^{\sim}$ (e.g. Kx)	FZ10$^{\sim}$ (e.g. Pb)
Iron [Dissolved]	mg/L	0.3^{+}	80th%ile	0.10	0.07	0.20	0.03
				1.60	**0.22**	**2.16**	**0.87**
Mercury [Dissolved]	mg/L	0.002^ or 0.0002^{+}	80th%ile	-	-	-	-
				0.0001	**0.0001**	**0.0001**	**0.0001**
Lead [Dissolved]	mg/L	0.1^ or 0.004^{+}	80th%ile	-	-	-	-
				0.001	**0.002**	**0.003**	**0.001**
Manganese [Dissolved]	mg/L	1.9^{+}	80th%ile	0.190	0.075	0.040	0.020
				0.704	**0.506**	**1.094**	**0.834**
Molybdenum [Dissolved]	mg/L	0.15^ or 0.034^{+}	80th%ile	-	-	-	-
				0.002	**0.011**	**0.003**	**0.005**
Nickel [Dissolved]	mg/L	1^ or 0.011^{+}	80th%ile	-	-	-	-
				0.003	**0.002**	**0.002**	**0.002**
Selenium [Dissolved]	mg/L	0.02^ or 0.01^{+}	80th%ile	-	-	-	-
				0.01	**0.01**	**0.03**	**0.01**
Uranium [Dissolved]	mg/L	0.2^ or 0.001^{+}	80th%ile	-	-	-	-
				0.003	**0.007**	**0.007**	**0.002**
Vanadium [Dissolved]	mg/L	0.01^{+}	80th%ile	-	-	-	-
				0.01	**0.01**	**0.03**	**0.01**
Zinc [Dissolved]	mg/L	20^ or 0.008^{+}	80th%ile	**0.060**	-	**0.161**	**0.110**
				0.018	**0.024**	0.040	0.053
TPH(C6-9)	mg/L	0.02^{+}	80th%ile	-	-	-	-
				0.02	**0.028**	**0.038**	**0.020**
TPH(C10-14)	mg/L	0.1^{+}	80th%ile	-	-	-	-
				0.05	**0.05**	**0.061**	**0.05**
TPH(C15-28)	mg/L	0.1^{+}	80th%ile	-	-	-	-
				0.149	**0.532**	**1.774**	**0.10**
TPH(C29-36)	mg/L	0.1^{+}	80th%ile	-	-	-	-
				0.247	**0.677**	**2.852**	**0.05**

* Draft EPP (2018) Zones are presented as default trigger [Bold] where greater than site-specific datasets.

$^{+}$ Based on model water conditions for coal mines in the Fitzroy basin.

^Water quality trigger values (low risk) for heavy metals and metalloids in livestock drinking water (ANZECC and ARMCANZ, 2000).

$^{\sim}$80th Percentile based on the Draft Regional Groundwater Chemistry Zones: Fitzroy-Capricorn Coast and Burdekin-Haughton-Don Regions for Alluvium Zone 6 (AZ6) – Curtis Coast; Cainozoic Deposits (including Deposits overlaying GAB) Zone 2 (CZ2) – Eastern Weathered Cainozoic Remnants; Earlier Basins partially underlying GAB Zone 11 (GZ11) – Eastern Bowen Coal Measures; and Fractured Rock Zone 10 (FZ10) – Eastern Fitzroy Trap Rocks.

Shaded Cells = Derived Guideline Value based on site-specific datasets available (Orange Environmental Pty Ltd, 2020) cognisant of DSITI (2017) *Using Monitoring Data to Assess Groundwater Quality and Potential Groundwater Impacts* and *Queensland Water Quality Guidelines* methodologies (i.e. based on > 8 samples, where available). Refer to **Tables 10-2 to 10-5**.

Note: Final triggers will be developed for each main hydrogeological unit DEHP (2009) and would generally align with the four WQO units prescribed in the draft *Regional Groundwater Chemistry Zones: Fitzroy-Capricorn Coast and Burdekin-Haughton-Don Regions* as above.

Until sufficient baseline data is available, the *Styx River, Shoalwater Creek and Water Park Creek Basins Environmental Values and Water Quality Objectives* for the following zones can also be used temporarily as trigger values where available (DEHP, 2014a):

- Zone 3 – Styx (shallow [5-20m] and moderate [20-40m] groundwater – 80th percentile values);
- Zone 10 – Uplands (very shallow [0-5m] and moderate [20-40m] groundwater – 80th percentile values);
- Zone 15 – Bison (shallow [5-20m] and moderate [20-40m] groundwater – 80th percentile values).

All metals and metalloids must be measured as total (unfiltered) and dissolved (<0.45 mm filtered). Contaminant limits for metals and metalloids are only considered to be exceeded if the results of dissolved metal or metalloid exceed the trigger level.

The quality characteristics and/or trigger levels may be reviewed if sufficient data is available to adequately demonstrate negligible environmental risk, and it may be determined that a reduced monitoring frequency is appropriate or that select parameters can be removed by amendment of the EA.

11.0 CONSIDERATION OF EPBC ACT GUIDELINES, SIGNIFICANT RESIDUAL IMPACTS AND OFFSETS

The *Significant Impact Guidelines 1.3: Coal Seam Gas and Large Coal Mining Developments—Impacts on Water Resources* prepared by the then DotE (2013) relevantly outline 'significant impact criteria' for such developments including a 'self-assessment' flowchart.

A 'significant impact' is defined as an impact which is:

> *… important, notable, or of consequence, having regard to its context or intensity. Whether or not an action is likely to have a significant impact depends upon the sensitivity, value, and quality of the water resource which is impacted, and upon the intensity, duration, magnitude and geographic extent of the impacts.*

The 'general criteria' are as follows, where the utility of a water resource for third parties (or value [e.g. EVs as discussed in **Section 6.2**]) must also be considered.

> *An action is likely to have a significant impact on a water resource if there is a real or not remote chance or possibility that it will directly or indirectly result in a change to:*
>
> - *the hydrology of a water resource;*
> - *the water quality of a water resource;*
>
> *that is of sufficient scale or intensity as to reduce the current or future utility of the water resource for third party users, including environmental and other public benefit outcomes, or to create a material risk of such reduction in utility occurring.*

Accordingly, Sections 5.3 and 5.4 of the Significant Impact Guidelines 1.3 relate specifically to guidance on changes to **hydrological characteristics** and **water quality**.

The EPBC Referral prepared by CDM Smith for the previously named Styx Coal Project (Styx Coal Pty Ltd and Fairway Coal Pty Ltd, 2016) relevantly concluded that a water resource, in relation to coal seam gas development and large coal mining development (sections 24D and 24E), was a matter likely to be significantly impacted. Subsequent notification of the decision was issued on 3 February 2017 that the proposed action is a Controlled Action, with a water resource, in relation to coal seam gas development and large coal mining development, as a relevant controlling provision.

A reconciliation against each of the hydrological and water quality characteristics stipulated in Sections 5.3 and 5.4 of the Significant Impact Guidelines 1.3 and how it has been relevantly considered in **this Report** for the CQC Project is provided in **Table 11-1**.

Where relevant, reference is made to the corresponding technical assessments undertaken by others, noting that collectively the assessment of the potential impacts, mitigation measures and any offsets for residual significant impacts are dealt with in a stand-alone section of the SEIS (prepared by Orange Environmental [2020]) that fully addresses the matters relevant to the controlling provisions. Nevertheless, the separate consideration of significant residual impacts (by others) and targeted groundwater monitoring, management, licensing and mitigation / make good measures are also referred to below.

A reconciliation against the IESC Information Guideline Checklist (for groundwater-related matters) is also described and tabulated in **Section 11.3** (**Table 11-2**).

Table 11-1
Significant Impact Criteria – Reconciliation Table for Groundwater-Related Matters

Criteria	Changes In / Are of	How Considered / Assessed in this Report	Where Addressed / Considered by Others
Hydrological Characteristics	*… water quantity, including the timing of variations in water quantity.*	Groundwater take/inflows, drawdown influence, baseflow impacts / enhanced leakage, predictions at features.	Sections 8.4 to 8.7, 8.9 and 9.1.
	…the integrity of hydrological or hydrogeological connections, including substantial structural damage (e.g. large scale subsidence)	Pit excavation, out-of-pit waste rock and coal rejects emplacement (final landforms) and in-pit backfilling.	Section 8.3.
	… the area or extent of a water resource	Groundwater drawdown influence, baseflow impacts/enhanced leakage, predictions at features.	Sections 8.5 to 8.7 and 8.9.
	… 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.	Potential impacts on groundwater quantity and associated surface water flow reductions, and groundwater quality, during mining and post mine closure, on utility.	Sections 6.2, 9.1, 9.2 and 9.3, and separate assessments by WRM Water & Environment (2020) and Eco Logical Australia (2020a)
	… flow regimes (volume, timing, duration and frequency of surface water flows);	Changes in water balance; baseflow impacts/enhanced leakage.	Sections 8.6, 9.1.1 and separate assessments by WRM Water & Environment (2020) and Eco Logical Australia (2020d)
	… recharge rates to groundwater;	Changes in hydraulic properties and interruption of rainfall recharge to excavated alluvium/regolith.	Sections 9.1.1 and 9.1.2.
	… aquifer pressure or pressure relationships between aquifers;	Direct groundwater inflows, changes in local groundwater flow directions (head gradients) and indirect groundwater inflows.	Sections 7.7.4 (vertical head gradients) 9.1.1 and 9.1.2, and Attachment 8 - Graph A8-54 (WMP31 VWP).
	… groundwater table and potentiometric surface levels;	Head plots and changes in local groundwater flow directions (head gradients).	Sections 5.4, 9.1.1, 9.1.2 and Attachments 13 to 15.
	… groundwater-surface water interactions;	Groundwater connectivity, drawdown influence, baseflow impacts/enhanced leakage, predictions at features.	Sections 7.7.6, 8.5 to 8.7, 8.9 and 8.11.2 (Table 8-8) and separate assessments by WRM Water & Environment (2020) and Eco Logical Australia (2020d)
	… river-floodplain connectivity;	Hydrological and landscape setting, surficial deposition processes, surficial geology and flood recharge.	Sections 3.3, 4.3, 4.6.1 and 7.5.4 and separate assessments by WRM Water & Environment (2020)
	… inter-aquifer connectivity;	Review of hydraulic properties, use of lateral connection groups (faults), quantitative uncertainty analysis and river bed conductance.	Sections 4.1, 5.6, 7.3, 7.7.6, 8.11.2, 8.11.3, 8.12.1 and 8.12.2.
	…coastal processes including changes to sediment movement or accretion, water circulation patterns, permanent alterations in tidal patterns, or substantial changes to water flows or water quality in estuaries	Tidal influence, geomorphology, water quality, and broad conceptualisation for freshwater-saline water interface.	Sections 3.2.7, 3.3, 4.6 and 6.3.2.
Water Quality Characteristics	*…there is a risk that the ability to achieve relevant local or regional water quality objectives would be materially compromised;*	Baseline groundwater quality, WQOs, potential impacts on groundwater quality, and groundwater quality triggers.	Sections 5.5, 6.2, 9.2, 10.1, 10.1.11 and 10.10 and separate assessments by WRM Water & Environment (2020) and Eco Logical Australia (2020a).
	… creates risks to human or animal health or to the condition of the natural environment as a result of the change in water quality;	EVs, WQOs and Potential impacts on EVs.	Sections 6.2 (6.2.3 and 6.2.4) and 9.3.

Table 11-1 (Continued)
Significant Impact Criteria – Reconciliation Table for Groundwater-Related Matters

Criteria	Changes In / Are of	How Considered in this Report	Where Addressed / Considered by Others
Water Quality Characteristics [*Cont*.]	… *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;*	EVs, WQOs and Potential impacts on EVs.	Sections 6.2 (6.2.6 and 6.2.8) and 9.3 and separate assessments by WRM Water & Environment (2020) and Eco Logical Australia (2020a).
	… *causes persistent organic chemicals, heavy metals, salt or other potentially harmful substances to accumulate in the environment;*	Geochemistry, water releases, and potential impacts on groundwater quality (during and post-mining).	Sections 4.5, 8.3.5, 9.2 and 10.3.1 and separate assessments by WRM Water & Environment (2020) and Eco Logical Australia (2020a).
	… *seriously affects the habitat or lifecycle of a native species dependent on a water resource;*	Environmental groundwater usage, EVs and WQOs, potential impacts on groundwater quality (during and post-mining).	Sections 5.3, 6.2 (6.2.1, 6.2.5), 9.2 and 9.3 and separate assessments by WRM Water & Environment (2020) and Eco Logical Australia (2020a).
	…*causes the establishment of an invasive species (or the spread of an existing invasive species) that is harmful to the ecosystem function of the water resource,*	Environmental groundwater usage, EVs and WQOs, potential impacts on groundwater quality (during and post-mining).	Sections 5.3, 6.2 (6.2.1, 6.2.5), 9.2 and 9.3 and separate assessments by WRM Water & Environment (2020) and Eco Logical Australia (2020a).
	… *there is a significant worsening of local water quality (where current local water quality is superior to local or regional water quality objectives);*	Baseline groundwater quality, WQOs, potential impacts on groundwater quality, and groundwater quality triggers.	Sections 5.5, 6.2, 9.2, 10.1, 10.1.11 and 10.10 and separate assessments by WRM Water & Environment (2020) and other thresholds by Eco Logical Australia (2020a).
	… *high quality water is released into an ecosystem which is adapted to a lower quality of water.*	Potential impacts on groundwater quality (post mine closure/equilibrium).	Section 9.2 and separate assessments by WRM Water & Environment (2020) [controlled releases] and Eco Logical Australia (2020a).
	… *predicted change in water quality is greater than that required for 'moderately to slightly disturbed' systems as described in the relevant local or regional water quality objectives (typically the 80% to 95% ecosystem protection guideline values listed in the Australian Water Quality Guidelines. Note that other thresholds may apply where changes in water quality may impact on other matters of national environmental significance, such as threatened species or ecological communities.*	Baseline groundwater quality, WQOs, potential impacts on groundwater quality, and groundwater quality triggers.	Sections 5.5, 6.2, 9.2, 10.1, 10.1.11 and 10.10 and separate assessments by WRM Water & Environment (2020) and other thresholds by Eco Logical Australia (2020a).

11.1 OVERVIEW OF OTHER MATTERS OF NATIONAL ENVIRONMENTAL SIGNIFICANCE (MNES)

In addition to water resources discussed above, other relevant controlling provisions under the EPBC Act (**Section 2.2.1**) for the CQC Project (EPBC 2016/7851) include:

- Great Barrier Reef Marine Park;
- World Heritage Properties;
- National Heritage Places;
- Listed threatened species and communities; and
- Listed migratory species.

Whilst the potential impacts on the parks, properties and places are assessed separately by others in the SEIS, for the purposes of clarity the following points are made:

- The Great Barrier Reef Marine National Park Zone MNP-21-1146 (Broad Sound area including the Bedwell Group, Wild Duck and Bamborough Island) is defined in Part 6 of the Great Barrier Reef Marine Park Zoning Plan 2003 (GBRMPA, 2004) under the *Commonwealth Great Barrier Reef Marine Park Act 1975* (**Section 2.2.2**). MNP-21-1146 is located approximately 40 km to the north-east of the CQC Project, and beyond the numerical groundwater model domain (**Section 7.4**).
- The Great Barrier Reef World Heritage Area (World Heritage Property) is located approximately 8 km downstream of ML 80187. The Great Barrier Reef World Heritage Area was taken to also meet the National Heritage criterion in accordance with subitem 1A(3) of Schedule 3 of the Commonwealth *Environment and Heritage Legislation Amendment Act (No.1) 2003* (National Heritage Place).
- The General Use Zone (at the mouth of the Styx River) is defined in Schedule 2 of the Marine Parks (Great Barrier Reef Coast) Zoning Plan 2004 under the *Queensland Marine Parks Act, 2004* (**Section 2.1.4**). The extent of the General Use Zone is, at its nearest point, generally coincidental with the boundary defined for the World Heritage Property and for the Broad Sound Fish Habitat Area (Plan No. FHA-047 gazetted by the Queensland Government Department of Primary Industries and Fisheries on 28 March 2008). FHA-047 was gazetted as a conservation measure for parts of the Broad Sound and adjoining estuarine systems recognising that the Broad Sound (QLD003) is listed as a Nationally Important Wetland in the DIWA[40].

This Report therefore has considered and assesses potential drawdown and storage change at the boundary of FHA-047 [and therefore approximately the boundary of DIWA Broad Sound] (at approximately 8 km), which can then also be applied/inferred for the General Use Zone, World Heritage Property and National Heritage Place.

As described in **Section 7.1.2** (**Table 7-1**), improvements to the numerical groundwater model included extension of the model domain to include a greater portion of the Broad Sound Declared Fish Habitat Area (FHA-047) and additional areas of FHA-047 in the Wellington Creek (including Stoodleigh Creek) catchments. Refinement of the model grid (unstructured) along watercourses, drainage features and wetlands for groundwater connectivity analysis was also completed.

As shown on **Graph 8-3**, the model predicted changes to the Styx River reaches (2 and 3) downstream of the CQC Project, and upstream of the Broad Sound Declared Fish Habitat Area (FHA-047), including the section traversing the historic mine workings at Styx No.3 State Coal Mine are less than 0.0003 m^3/s for the combined 6.1 km length. When considering the downstream Styx River reaches are subject to tidal influences as well as rainfall runoff from downstream contributing catchments, including Granite Creek and Montrose Creek, such model predicted volumetric differentials are considered negligible and would be indiscernible.

Further to this, the Uncertainty Analysis demonstrated that the model predicted storage changes for the Broad Sound Fish Habitat Area was effectively nil (**Table 8-8**).

The potential impacts on listed threatened species and communities and migratory species are assessed separately by Eco Logical Australia Pty Ltd (2020a) and proposed offsets are considered separately by others.

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[40] It is noted that the DIWA Broad Sound [QLD003] polygon at its nearest point is at a slightly greater distance downstream of FHA-047.

11.2 SIGNIFICANT RESIDUAL IMPACTS AND OFFSETS

The assessment of significant residual impacts cognisant of the *Queensland Environmental Offsets Policy Significant Residual Impact Guideline* (DEHP, 2014b) is undertaken separately by Orange Environmental (2020) and offsets by others, with relevant input from Eco Logical Australia Pty Ltd (2020a) based on the numerical groundwater model predictions, potential impacts on groundwater resources, dependent assets and environmental values, and monitoring, management, licensing, review and mitigation measures outlined in **Sections 7.0 to 10.0** and is not considered further in **this Report**.

No supplementary water inputs are proposed by CQCPL for the CQC Project, therefore do not require consideration for future groundwater model validation (i.e. as a potential future input to streamflow).

11.3 IESC INFORMATION GUIDELINE CHECKLIST

A reconciliation against the IESC Information Guidelines checklists for groundwater-related matters is provided in **Table 11-2**. References to assessments undertaken by others are included where relevant.

Table 11-2
IESC Information Guidelines Checklist – Reconciliation Table for Groundwater-Related Matters

Category	Requirement	How Considered/ Addressed
Description of the Proposal	Provide a regional overview of the proposed project area including a description of the geological basin; coal resource; surface water catchments; groundwater systems; water-dependent assets; and past, present and reasonably foreseeable coal mining and CSG developments.	Sections 3.0, 4.0 and 5.0
	Describe the proposal's location, purpose, scale, duration, disturbance area, and the means by which it is likely to have a significant impact on water resources and water-dependent assets.	Sections 1.0, 5.0, 8.0 and 11.0
	Describe the statutory context, including information on the proposal's status within the regulatory assessment process and any applicable water management policies or regulations.	Section 2.0
	Describe how impacted water resources are currently being regulated under state or Commonwealth law, including whether there are any applicable standard conditions.	Sections 2.0 and 10.9
Risk Assessment	Identify and assess all potential environmental risks to water resources and water-related assets, and their possible impacts. In selecting a risk assessment approach consideration should be given to the complexity of the project, and the probability and potential consequences of risks.	Sections 6.0, 8.11 and 8.12
	Incorporate causal mechanisms and pathways identified in the risk assessment in conceptual and numerical modelling. Use the results of these models to update the risk assessment.	Sections 6.0, 7.0 and 8.0
	Assess risks following the implementation of any proposed mitigation and management options to determine if these will reduce risks to an acceptable level based on the identified environmental objectives.	Sections 9.0, 10.0 and 11.0
	The risk assessment should include an assessment of: – all potential cumulative impacts which could affect water resources and water-related assets, and – mitigation and management options which the proponent could implement to reduce these impacts.	Sections 8.10 and 10.0

Table 11-2 (Continued)
IESC Information Guidelines Checklist – Reconciliation Table for Groundwater-Related Matters

Category	Requirement	How Considered/ Addressed
Groundwater – Context and Conceptualisation	Describe and map geology at an appropriate level of horizontal and vertical resolution including: – definition of the geological sequence(s) in the area, with names and descriptions of the formations and accompanying surface geology, cross-sections and any relevant field data. – geological maps appropriately annotated with symbols that denote fault type, throw and the parts of sequences the faults intersect or displace.	Sections 4.0, 5.0 and 6.0
	Provide data to demonstrate the varying depths to the hydrogeological units and associated standing water levels or potentiometric heads, including direction of groundwater flow, contour maps, and hydrographs. All boreholes used to provide this data should have been surveyed.	Sections 4.0 and 5.0
	Define and describe or characterise significant geological structures (e.g. faults, folds, intrusives) and associated fracturing in the area and their influence on groundwater – particularly groundwater flow, discharge or recharge. – Site-specific studies (e.g. geophysical, coring/ wireline logging etc.) should give consideration to characterising and detailing the local stress regime and fault structure (e.g. damage zone size, open/closed along fault plane, presence of clay/shale smear, fault jogs or splays). – Discussion on how this fits into the fault's potential influence on regional-scale groundwater conditions should also be included.	Sections 4.0, 6.0 and 8.12
	Provide hydrochemical (e.g. acidity/alkalinity, electrical conductivity, metals, and major ions) and environmental tracer (e.g. stable isotopes of water, tritium, helium, strontium isotopes, etc.) characterisation to identify sources of water, recharge rates, transit times in aquifers, connectivity between geological units and groundwater discharge locations.	Sections 5.5 and 6.0
	Provide site-specific values for hydraulic parameters (e.g. vertical and horizontal hydraulic conductivity and specific yield or specific storage characteristics including the data from which these parameters were derived) for each relevant hydrogeological unit. In situ observations of these parameters should be sufficient to characterise the heterogeneity of these properties for modelling.	Sections 5.6, 7.7.3 and 8.11.2 and Attachments 7, 9 and 11
	Describe the likely recharge, discharge and flow pathways for all hydrogeological units likely to be impacted by the proposed development.	Section 6.3
	Provide time series level and water quality data representative of seasonal and climatic cycles.	Section 5.0
	Assess the frequency (and time lags if any), location, volume and direction of interactions between water resources, including surface water/groundwater connectivity, inter-aquifer connectivity and connectivity with sea water.	Sections 3.3 and 5.0
Groundwater – Analytical and Numerical Modelling	Provide a detailed description of all analytical and/or numerical models used, and any methods and evidence (e.g. expert opinion, analogue sites) employed in addition to modelling.	Section 6.0, 7.0 and 8.0
	Provide an explanation of the model conceptualisation of the hydrogeological system or systems, including multiple conceptual models if appropriate. Key assumptions and model limitations and any consequences should also be described.	Sections 6.0 and 8.12
	Undertaken groundwater modelling in accordance with the Australian Groundwater Modelling Guidelines (Barnett *et al*. 2012), including independent peer review.	Sections 7.0, 8.0 and Attachments 10 and 11
	Consider a variety of boundary conditions across the model domain, including constant head or general head boundaries, river cells and drains, to enable a comparison of groundwater model outputs to seasonal field observations.	Sections 7.2, 7.5 and 8.11.6

Table 11-2 (Continued)
IESC Information Guidelines Checklist – Reconciliation Table for Groundwater-Related Matters

Category	Requirement	How Considered/ Addressed
Groundwater – Analytical and Numerical Modelling (Continued)	Calibrate models with adequate monitoring data, ideally with calibration targets related to model prediction (e.g. use baseflow calibration targets where predicting changes to baseflow).	Sections 5.0 and 7.7
	Undertake sensitivity analysis and uncertainty analysis of boundary conditions and hydraulic and storage parameters, and justify the conditions applied in the final groundwater model (see Middlemis and Peeters [in press]).	Section 8.11, 8.12 and Attachment 11
	Describe each hydrogeological unit as incorporated in the groundwater model, including the thickness, storage and hydraulic characteristics, and linkages between units, if any.	Sections 4.0, 5.0, 6.0 and 7.0
	Provide an assessment of the quality of, and risks and uncertainty inherent in, the data used to establish baseline conditions and in modelling, particularly with respect to predicted potential impact scenarios.	Sections 8.10, 8.11 and 8.12
	Describe the existing recharge/discharge pathways of the units and the changes that are predicted to occur upon commencement, throughout, and after completion of the proposed project.	Sections 6.0, 7.0 and 8.0
	Undertake an uncertainty analysis of model construction, data, conceptualisation and predictions (see Middlemis and Peeters [in press]).	Section 8.11, 8.12 and Attachment 11
	Describe the various stages of the proposed project (construction, operation and rehabilitation) and their incorporation into the groundwater model. Provide predictions of water level and/or pressure declines and recovery in each hydrogeological unit for the life of the project and beyond, including surface contour maps for all hydrogeological units.	Sections 8.1, 8.2, 8.3, 8.5, 8.9 and 9.0
	Provide a program for review and update of models as more data and information become available, including reporting requirements.	Sections 10.7 and 10.9
	Identify the volumes of water predicted to be taken annually with an indication of the proportion supplied from each hydrogeological unit.	Sections 8.4, 8.5, 8.6, 8.7 and 10.3
	Undertake model verification with past and/or existing site monitoring data.	Section 8.2.1
Groundwater – Impacts to Water Resources and Water-Dependent Assets	Provide an assessment of the potential impacts of the proposal, including how impacts are predicted to change over time and any residual long-term impacts. Consider and describe: – any hydrogeological units that will be directly or indirectly dewatered or depressurised, including the extent of impact on hydrological interactions between water resources, surface water/groundwater connectivity, inter-aquifer connectivity and connectivity with sea water. – the effects of dewatering and depressurisation (including lateral effects) on water resources, water-dependent assets, groundwater, flow direction and surface topography, including resultant impacts on the groundwater balance. – the potential impacts on hydraulic and storage properties of hydrogeological units, including changes in storage, potential for physical transmission of water within and between units, and estimates of likelihood of leakage of contaminants through hydrogeological units. – the possible fracturing of and other damage to confining layers. – For each relevant hydrogeological unit, the proportional increase in groundwater use and impacts as a consequence of the proposed project, including an assessment of any consequential increase in demand for groundwater from towns or other industries resulting from associated population or economic growth due to the proposal.	Section 9.0
	Describe the water resources and water-dependent assets that will be directly impacted by mining or CSG operations, including hydrogeological units that will be exposed/partially removed by open cut mining and/or underground mining.	Sections 5.0, 8.0 and 9.0

Table 11-2 (Continued)
IESC Information Guidelines Checklist – Reconciliation Table for Groundwater-Related Matters

Category	Requirement	How Considered/ Addressed
Groundwater – Impacts to Water Resources and Water-Dependent Assets (Continued)	For each potentially impacted water resource, provide a clear description of the impact to the resource, the resultant impact to any water-dependent assets dependent on the resource, and the consequence or significance of the impact.	Sections 9.0 and 11.0
	Describe existing water quality guidelines, environmental flow objectives and other requirements (e.g. water planning rules) for the groundwater basin(s) within which the development proposal is based.	Sections 2.0 and 6.2
	Provide an assessment of the cumulative impact of the proposal on groundwater when all developments (past, present and/or reasonably foreseeable) are considered in combination.	Section 8.10
	Describe proposed mitigation and management actions for each significant impact identified, including any proposed mitigation or offset measures for long-term impacts post mining.	Section 10.0
	Provide a description and assessment of the adequacy of proposed measures to prevent/minimise impacts on water resources and water-dependent assets.	Section 10.0
Groundwater – Data and Monitoring	Provide sufficient data on physical aquifer parameters and hydrogeochemistry to establish pre-development conditions, including fluctuations in groundwater levels at time intervals relevant to aquifer processes.	Sections 4.5 and 5.0
	Provide long-term groundwater monitoring data, including a comprehensive assessment of all relevant chemical parameters to inform changes in groundwater quality and detect potential contamination events.	Section 5.0
	Develop and describe a robust groundwater monitoring program using dedicated groundwater monitoring wells – including nested arrays where there may be connectivity between hydrogeological units – and targeting specific aquifers, providing an understanding of the groundwater regime, recharge and discharge processes and identifying changes over time	Sections 5.0 and 10.1
	Ensure water quality monitoring complies with relevant National Water Quality Management Strategy (NWQMS) guidelines (ANZG 2018) and relevant legislated state protocols (e.g. QLD Government 2013).	Section 10.0
	Develop and describe proposed targeted field programs to address key areas of uncertainty, such as the hydraulic connectivity between geological formations, the sources of groundwater sustaining GDEs, the hydraulic properties of significant faults, fracture networks and aquitards in the impacted system, etc., where appropriate.	Sections 4.0, 5.0, 10.1 and Attachments 5, 6, 7 and 9.
Surface Water – Context and Conceptualisation		[*Surface Water Assessed Separately by WRM Water & Environment, 2020*]
Surface Water – Analytical and Numerical Modelling		
Surface Water – Impacts to Water Resources and Water-Dependent Assets		
Surface Water – Data and Monitoring		
Water-Dependent Assets – Context and Conceptualisation		[*Ecology and other Water-Dependent Assets Assessed Separately by Eco Logical Australia Pty Ltd (2020a)*]
Water-Dependent Assets – Impacts, Risk Assessment and Management of Risks		
Water-Dependent Assets – Data and Monitoring		
Water and Salt Balance, and Water Quality		[*Surface Water Assessed Separately by WRM Water & Environment, 2020*]

Table 11-2 (Continued)
IESC Information Guidelines Checklist – Reconciliation Table for Groundwater-Related Matters

Category	Requirement	How Considered/ Addressed
Cumulative Impacts – Context and Conceptualisation		Sections 6.0 and 8.10
Cumulative Impacts – Impacts		Section 8.10
Cumulative Impacts – Mitigation, Monitoring and Management		Section 10.0
Subsidence – Underground Coal Mines and Coal Seam Gas		Section 8.3
Final Landforms and Voids – Coal Mines		Section 8.3.6
Acid-Forming Materials and Other Contaminants of Concern		Section 4.5
CSG Well Construction and Operation		Not Applicable

12.0 CONCLUSIONS

This Report has been prepared for the Central Queensland Coal Project Supplementary EIS Version 3 – Responses to Submissions. Improvements have been made to the previous numerical groundwater model to reflect the peer review outcomes, incorporate available datasets and consider feedback sought during consultation with Government departments, including consideration of published guidelines (and explanatory notes) released by the IESC.

It is recognised that previous assessments for the CQC Project have included the compilation and analysis of comprehensive baseline groundwater datasets across several campaigns commencing first in 2010-11 with increasing intensity more recently (2017-2019), including targeted groundwater and related investigations, including hydrological, geological, geochemical, geomorphological and ecological (subterranean, aquatic and terrestrial) assessments and review.

Based on the baseline groundwater datasets (which continue to be developed cognisant of contemporary Commonwealth and State guideline requirements) and recognising the regulatory framework and relevant environmental values and water quality objectives (including recent updates proposed by the Qld Government in consultation materials), the conceptual groundwater model has been reviewed and refined to inform the improvements to the numerical groundwater model.

Open cut mining at the CQC Project would target the Early Cretaceous Styx Coal Measures within ML 80187. Mining activities would operate for approximately 18 years with progressive backfilling of the advancing open cut; the final void would be backfilled upon completion of ROM coal mining. The improved numerical groundwater model has been designed and constructed to allow application of key processes (i.e. pit excavation, in-pit backfilling, and post-mining landforms) to predict groundwater take/inflows, groundwater drawdown influence and consequential baseflow impacts, enhanced leakage, and/or impacts on groundwater users or dependent assets. The indicative final landform design surface (referred as Landform [LF3]), has been used for the purposes of the numerical groundwater model.

During the implementation of the most recent improvements to the numerical groundwater model, including development of a robust uncertainty analysis approach, consultation with the DES has occurred with consideration of relevant feedback, in parallel with a progressive independent peer review by AGE Consultants.

The staged independent peer review relevantly concluded that appropriate parameter identifiability and uncertainty analysis had been completed (AGE Consultants, Stage 3, 7 May 2020), however it was recognised that inevitably any assessment of whether or not a modelling study meets a set of criteria is subjective. Therefore, a number of areas for further improvement were recommended, and have been duly considered and responded to within **this Report** to demonstrate that following the robust uncertainty analysis, extensive parameter analysis and testing, and supporting justification for model concepts and complexity, improvements have been made appropriately and the predictions presented by the CQC-LF3 Groundwater Model are fit-for-purpose and achieves the overall target model confidence level classification.

Ultimately, the final peer review (**Attachment 2**) concludes (AGE Consultants Stage 4, 16 July 2020):

> *The modelling work has generally been completed in line with the Guiding Principles included in the Australian Groundwater Modelling Guidelines and in the IESC Uncertainty Analysis Guidance Note and we have not identified any fundamental flaws in the work which are likely to significantly effect model predictions.*

Outcomes of the Improved Numerical Groundwater Modelling

Based on the improved numerical groundwater modelling (CQC-LF3) there is expected to be:

- approximately 0.5 ML/day average groundwater take during the operational life of the CQC Project, with predicted inflow to the open cut steadily increasing as the pit is developed and depth increases to the east, up to approximately 1.2 ML/day (averaged over a quarterly interval);
- substantial reduction in potentiometric head in the Styx Coal Measures (overburden and interburden) and to a lesser extent in the Styx Coal Measures (underburden) and Back Creek Group in the near vicinity of the open cut mining operation, extending to lesser magnitudes (i.e. <2 m) beyond the open cut extent up to approximately:
  - 3.5 km in the north;
  - 5 km in the north-east (at depth); and
  - 3 km in the south-east;
- some temporal drawdown predicted in the Cenozoic sediments in the near vicinity of the open cut mining operation, where the saturated water table is present (albeit gradual and localised), and is predicted to gradually recover post-mining;
- negligible changes in natural baseflow to and/or leakage from surface water systems, as a consequence of predicted reductions in potentiometric head and temporal drawdown in the near vicinity of the open cut mining operation, with predicted volumetric differentials in baseflow to and/or enhanced leakage as follows (presented as peak estimates for the relevant averaged period):
  - up to approximately 0.008-0.009 m^3/s from Tooloombah Creek upstream of the Deep Creek confluence (9.3 km reach);
  - up to approximately 0.005-0.006 m^3/s from Deep Creek (17.5 km reach);
  - less than 0.0002 m^3/s from Tooloombah Creek downstream of the Deep Creek confluence (1.7 km reach); and
  - less than 0.0003 m^3/s from the Styx River (6.1 km reach);
- negligible impact on groundwater yield, levels and quality of private landholder bores in all hydrogeological units, with the exception of one private landholder bore (BH28) screened in the deeper consolidated aquifer immediately south-west of ML 80187;
- no appreciable change in groundwater quality as a result of the CQC Project is predicted both:
  - during the open cut mining operation as the advancing pit would remain as a temporal and localised sink to which surrounding groundwaters would flow toward; and
  - in the long-term as the voids would be backfilled (in accordance with a Mineral Waste Management Plan) and groundwater levels substantially recover over many decades by enhanced rainfall recharge/infiltration at the surface across the backfill spoil and emplacement areas.

Whilst available datasets and records suggest substantial recovery of groundwater pressures and levels at the historic mine workings at Ogmore and Bowman has already occurred, it is expected they will continue to gradually recover over the coming decades as well.

Cumulatively, the predicted groundwater drawdown effects as a result of the CQC Project do not extend as far as the historic Ogmore mine workings (some 8 km to the north and downstream beneath the Styx River) to result in any superposition effects and therefore is not expected to result in any discernible change to the location of the freshwater-saltwater interface.

That is, even if the interface was to be transient (or static) north of the historic Ogmore workings, there would not be expected to be any discernible change due to the CQC Project alone. The cumulative effects of the historic mine workings at Bowman (beyond those predicted for the CQC Project alone) are predicted to be negligible given the limited extent and proximity of the historic workings in the north, and continued recovery since the cessation of mining.

The potential impacts of the CQC Project on surface water resources are assessed and presented separately by Orange Environmental Pty Ltd (2020) and WRM Water & Environment (2020).

Similarly, the potential impacts on groundwater dependent ecosystems (including combined hydrogeological and hydrological changes i.e. catchment excision and controlled releases) are assessed and presented separately by Orange Environmental Pty Ltd (2020) and Eco Logical Australia Pty Ltd (2020a).

Key Monitoring and Management Recommendations

The following key groundwater-related monitoring recommendations are made going forward:

- CQCPL should consider installing an additional groundwater monitoring bore (deep standpipe) to the north / north-east of Open Cut 2, but to the west of the mapped fault (e.g. between WMP05 and WMP10) and south of the historic mine workings at Ogmore within the first three (3) years of the operation for the purposes of model prediction validation and adaptive management[41];
- CQCPL should continue baseline groundwater level measurements and groundwater quality sampling as outlined in the proposed groundwater monitoring program in **this Report**, with the objective to augment current statistical datasets to inform the final (or future) EA condition investigation trigger levels; and
- CQCPL should continue baseline surface water flow gauging and surface water quality sampling as outlined in the proposed groundwater monitoring program in **this Report**, with the objective to augment current datasets to inform the final (or future) EA conditions, and provide the opportunity for future groundwater model validation.

It is understood future monitoring programs would be outlined and integrated where relevant with the suite of other management plans developed for the CQC Project including:

- Water Management Plan;
- Erosion and Sediment Control Plan(s);
- Mineral Waste Management Plan;
- Groundwater Dependent Ecosystem Management and Monitoring Plan; and
- Receiving Environment Monitoring Program.

The integration of the above would be finalised in the groundwater monitoring program prepared in accordance with the proposed EA condition, developed by a suitably qualified person, and submitted to the administering authority for review and comment, including timeframes for staged installation and commissioning for the proposed supplementary groundwater monitoring locations as required.

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[41] In April 2020, CQCPL installed WMP21B to a total depth of approximately 95 m with screen targeting the overburden of the Styx Coal Measures in line with the key monitoring and management recommendation.

13.0 REFERENCES

AGE Consultants (2006) *Ensham Central Project Environmental Impact Assessment – Groundwater Impact Assessment.*

AGE Consultants (2018) *Middlemount Coal Mine Western Extension Project Groundwater Assessment*. September 2018.

AGE Consultants (2019) *Peer Review of Styx Groundwater Model*. 5 February 2019.

Alluvium Consulting (2019) *Critical Review of Climate Change and Water Modelling in Queensland – Final Report*. Prepared collaboratively with CSIRO and University of Newcastle on behalf of the Queensland Water Modelling Network, Queensland Government, Brisbane. November 2019.

Alpha-Mine Planning 4U (2018a) *Schedule Simulation – Styx Contractor Option V14*. *File: 20190919 Styx_Schedule_Analysis_V14-17092018.ppt*

Alpha-Mine Planning 4U (2018b) *Styx Dumps*. Presentation dated 29 September 2018. 28pp.

Alpha-Mine Planning 4U (2020) *Styx SEIS V3 Dumps*. Presentation dated 20 January 2020. 28pp.

ALS (2017) *Central Queensland Coal Project Supplementary Environmental Impact Statement: Appendix 3 – Soil Survey Results*.

ALS Water Science Group (2011) *Waratah Coal Mine Project – Styx River Catchment Aquatic Baseline Monitoring Program*. Prepared for Yeats Consulting. August 2011.

Arrow Energy N.L. (2005) *Styx River 1 Well Completion Report ATP700P*. Report prepared by B. Pinder (Senior Geologist).

Arrow Energy N.L. (2007[a]) *Styx-River 2 Well Completion Report ATP700P*. Report prepared by N. Oberhardt (Geologist).

Arrow Energy N.L. (2007[b]) *Styx River-3 Well Completion Report ATP700P*. Report prepared by N. Oberhardt (Geologist).

Arrow Energy Pty Ltd (2012) *Bowen Gas Project Environmental Impact Statement – Appendix M Groundwater Model Technical Report*. October 2012.

AS/NZS ISO 31000:2009. *Risk management—Principles and guidelines.* Standards Australia, Sydney.

Ausenco-Norwest (2012) *Groundwater Model, Northern Bowen Basin Regional Model Impact Predictions, Queensland, Australia*. Arrow Energy Pty Ltd.

Australian Mining Engineering Consultants (AMEC) (2014) *Groundwater Investigations for the Styx Trial Pit*. December 2014. Revised September 2019.

Australian Mining Engineering Consultants (AMEC) (2017) *Geotechnical Report for the Styx Coal Project.* April 2017.

Australian Mining Engineering Consultants (AMEC) (2018) *Appendix A – Geological Report* in Cardno (2018) *Pits Adjacent to Bruce Highway – Slope Stability Assessment. Central Queensland Coal Project.* 10 May 2018.

Australian Mining Engineering Consultants (AMEC) (2019) *Groundwater Report for the Central Queensland Coal Project.* November 2019.

Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*.

Australian and New Zealand Guidelines (ANZG) (2018) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. Australian and New Zealand Governments and Australian State and Territory Governments, Canberra ACT, Australia.

Barnett B, Townley LR, Post V, Evans RE, Hunt RJ, Peeters L, Richardson S, Werner AD, Knapton A and Boronkay A (2012). Australian groundwater modelling guidelines. Waterlines report no. 82. Canberra, National Water Commission.

Barron, O., Crosbie, R., Dawes, W., Charles, S., Pickett, T. and Donn, M. (2012). *Climatic Controls on Diffuse Groundwater Recharge Across Australia*. Journal of Hydrology and Earth System Sciences, 16, 4557-4570.

Bouwer, H. and Rice, R.C. (1976) *A slug test method for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells*. Water Resources Research, Vol. 12, No. 3, pp. 423-428.

Bowen H.J.M. (1979) *Environmental Chemistry of the Elements*. Academic Press, London.

Canadell, J., Jackson, R.B., Ehleringer, J.R., Mooney, H.A., Sala, O.E., and Schulze, E.D. (1996) *Maximum Rooting Depth of Vegetation Types at the Global Scale*. In *Oecologia* (1996) 108: pp. 583-595.

Cardno (2018) *Pits Adjacent to Bruce Highway – Slope Stability Assessment. Central Queensland Coal* Project. 10 May 2018.

Carpenter, L.M. (1991) *Livingstone: A History of the Shire of Livingstone, Yeppoon*. Boolarong Publications.

CCS Surveys Pty Ltd (2020) *Central Queensland Coal Styx Coal South 10607-3-D3 Survey Report*. May 2020.

CDM Smith (2013) *Springsure Creek Coal Mine Project: EIS Chapter 9 – Groundwater*. Report for Springsure Creek Coal Pty Ltd.

CDM Smith (2016) *Styx Coal Project Initial Advice Statement.* December 2016.

CDM Smith (2017a) *Central Queensland Coal Project Environmental Impact Statement*. October 2017.

CDM Smith (2017b) *Central Queensland Coal Project Groundwater Technical Report*. 30 June 2017.

CDM Smith (2018a) *Central Queensland Coal Project Supplementary Environmental Impact Statement: Appendix 6 – Groundwater Technical Report*. 17 May 2018.

CDM Smith (2018b) *Central Queensland Coal Project Supplementary Environmental Impact Statement: Chapter 10 – Groundwater.* 18 May 2018.

CDM Smith (2018c) *Central Queensland Coal Project Supplementary Environmental Impact Statement*. May 2018.

CDM Smith (2018d) *Central Queensland Coal Project Supplementary Environmental Impact Statement: Appendix 6 – Groundwater Technical Report, Draft*. 30 November 2018.

CDM Smith (2018e) *Central Queensland Coal Project Supplementary Environmental Impact Statement*. December 2018.

CDM Smith (2018f) *Central Queensland Coal Project Supplementary Environmental Impact Statement: Chapter 10 – Groundwater.* December 2018.

CDM Smith (2018g) *Central Queensland Coal Project Appendix A6 – Groundwater Technical Report*. 20 December 2018.

CDM Smith (2018h) *Central Queensland Coal Project Supplementary Environmental Impact Statement: Chapter 9 – Surface Water.* December 2018.

CDM Smith (2018i) *Central Queensland Coal Project Supplementary Environmental Impact Statement: Chapter 18 – Cultural Heritage.* December 2018.

CDM Smith (2018j) *Central Queensland Coal Project Appendix A5a – Surface Water and Groundwater Quality Results*. *Landholder Bore Overview*.

CDM Smith (2018k) *Central Queensland Coal Project Supplementary Environmental Impact Statement: Chapter 8 – Waste Rock and Rejects.* December 2018.

Central Queensland Coal Pty Ltd (CQCPL) (2020a) *CQC Surface Water Monitoring Survey Report*. 13 March 2020.

Central Queensland Coal Pty Ltd (CQCPL) (2020b) *Fault Investigation – Eastern Styx Coal Measures*. Memorandum dated 15 May 2020.

Central Queensland Coal Pty Ltd and Fairway Coal Pty Ltd (CQCPL & FCPL) (2018) *Review of Waterway Barrier Works Mapping Intersecting the Central Queensland Coal Project (ML 80187)*. Appendix 21 in the *Central Queensland Coal Project Supplementary Environmental Impact Statement.* 30 November 2018.

Chong, E.S.C. (1964) *Geological Survey Reports – Coal Resources Styx River Coalfield (Styx No.3 State Mine Area).* Queensland Government Mining Journal, June 1964.

Clark, D., McPherson, A. and Collins, C. (2011) *Australia's Seismogenic Neotectonic Record*. Geoscience Australia 2011/11.

Coffey (2014) *Supplementary Groundwater Assessment Arrow Energy Bowen Gas Project Supplementary Report to the EIS*. 17 April 2014.

Commonwealth of Australia (2018) *Reef 2050 Long-Term Sustainability Plan*. July 2018.

Cookson I.C. and Dettmann, M.E. (1958) *Some Trilete Spores from Upper Mesozoic Deposits in the Eastern Australian Region*. Proc. Roy. Soc. Vic., 70, 95-128.

Cookson I.C. and Eisenach A. (1958) *Microplankton from Australia and New Guinea Upper Mesozoic Sediments*. Proc. Roy. Soc. Vic., 70, 19-78.

Cooper, H.H. and Jacob, C.E. (1946) *A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well Field History*. American Geophysical Union Eos Transactions, Vol. 27, pp. 526-534.

Crosbie R.S., Morrow D., Cresswell R.G., Leaney F.W., Lamontagne S. and Lefournour M. (2012) *New Insights into the Chemical and Isotopic Composition of Rainfall across Australia*. CSIRO Water for a Healthy Country Flagship, Australia.

Department of Agriculture and Fisheries (DAF) (2017*) Queensland Agricultural Land Audit – Annual Addendum 2017*. October 2017.

Department of Agriculture, Fisheries and Forestry (DAFF) (2013*) Queensland Agricultural Land Audit – May 2013*.

Department of Agriculture, Fisheries and Forestry (DAFF) (2014*) Queensland Agricultural Land Audit – Annual Addendum 2014*.

Department of Environment and Heritage Protection (DEHP) (2014a) *Styx River, Shoalwater Creek and Water Park Basins Environmental Values and Water Quality Objectives – Basins 127, 128 and 129, including all waters of the Styx River, Shoalwater Creek and Water Park Basins and Adjacent Coastal Waters*. November 2014.

Department of Environment and Heritage Protection (DEHP) (2014b) *Queensland Environmental Offsets Policy Significant Residual Impact Guideline, Nature Conservation Act 1992, Environmental Protection Act 1994, Marine Parks Act 2004*. December 2014.

Department of Environment and Heritage Protection (DEHP) (2016) *EIS Information Guideline – Groundwater Dependent Ecosystems*.

Department of Environment and Science (DES) (2017) *Guideline Baseline Assessments*. 5 July 2017.

Department of Environment and Science (DES) (2019) *Great Barrier Reef River Basins: End-of-Basin Load Water Quality Objectives. Great Barrier Reef Basins 101-138 (excluding Basins 115, 123, 131 and 139)*. September 2019.

Department of Natural Resources and Mines (DNRM) (2001) *1:100,000 Scale Geological Series Rookwood Sheet 8851*. First Edition.

Department of Natural Resources, Mines and Energy (DNRME) (2019) *Underground Water Impact Report for the Surat Cumulative Management Area – July 2019*. Office of Groundwater Impact Assessment.

Department of Natural Resources, Mines and Water (DNRMW) (2006) *1:100,000 Scale Geological Series Marlborough Sheet 8852*.

Department of Science, Information Technology and Innovation (DSITI) (2017) *Draft Environmental Values and Water Quality Guidelines: Fitzroy Basin Fresh, Estuarine and Marine Waters, including Keppel Bay*. Draft for Consultation, March 2017.

Department of Science, Information Technology, Innovation and Arts (DSITIA) (2015) *Receiving Environment Monitoring Program Guideline – For Use with Environmentally Relevant Activities under the Environmental Protection Act 1994.* ESR/2016/2399 Version 2.01. 9 June 2015.

Department of State Development, Infrastructure and Planning (DSDIP) (2013) *Central Queensland Regional Plan*. October 2013.

Department of the Environment (DotE) (2013) *Significant Impact Guidelines 1.3: Coal Seam Gas and Large Coal Mining Developments— Impacts on Water Resources.* December 2013.

Doherty, J. and Hunt, R.J. (2009) *Two Easily Calculated Statistics for Evaluating Parameter Identifiability and Error Reduction*. Journal of Hydrology. 366, 119-127.

Doherty, J. (2015) *Calibration and Uncertainty Analysis for Complex Environmental Models*. Watermark Numerical Computing.

Domenico, P.A. and Schwartz, F.W. (1990) *Physical and Chemical Hydrogeology*. John Wiley & Sons, New York, 824 pp.

Environmental Protection Authority (EPA) (2003) *WA EPA Guidance Statement No. 54, Consideration of Subterranean Fauna in Groundwater and Caves during Environmental Impact Assessment in Western Australia*.

Eamus, D. (2009) *Identifying Groundwater Dependent Ecosystems: A Guide for Land and Water Managers*. Land and Water Australia Research Report.

Eco Logical Australia Pty Ltd (2020a) *Technical Report - Aquatic Ecology, Groundwater Dependent Ecosystems, Marine Ecology and the Great Barrier Reef. Central Queensland Coal Project*. Prepared on behalf of Orange Environmental Pty Ltd and CQCPL.

Eco Logical Australia Pty Ltd (2020b) *Draft Groundwater Dependent Ecosystem Management and Monitoring Plan*. *Central Queensland Coal Project.* Prepared on behalf of Orange Environmental Pty Ltd and CQCPL.

Eco Logical Australia Pty Ltd (2020c) *Draft Receiving Environment Monitoring Program. Central Queensland Coal Project*. Prepared on behalf of Orange Environmental Pty Ltd and CQCPL.

Eco Logical Australia Pty Ltd (2020d) *Surface Water – Groundwater Integrated Model. Central Queensland Coal Project.* Prepared on behalf of Orange Environmental Pty Ltd and CQCPL.

Engeny Water Management (2020) *Conceptual Erosion and Sediment Control Plan. Central Queensland Coal Project.* 31 March 2020.

Environmental Protection Authority (EPA) (2007) *WA EPA Guidance Statement No. 54a, Sampling Methods and Survey Considerations for Subterranean Fauna in Western Australia*.

Esterle, J. and Sliwa, R. (2002) *Bowen Basin Supermodel 2000*. ACARP Project C9021, Exploration and Mining Report 976C, CSIRO Exploration and Mining.

Flodin, E.A., Aydin, A., Durlofsky, L.J. and Yeten, B. (2001) *Representation of Fault Zone Permeability in Reservoir Flow Models*. SPE Annual Technical Conference and Exhibition. New Orleans, Louisiana.

Fluvial Systems Pty Ltd (2020) *Central Queensland Coal Project Environmental Impact Statement Supplementary Study Report Fluvial Geomorphology.* May 2020. Draft.

Geoscience Australia (2004) *Australia's River Basins 1997-Product User Guide*. Published by Geoscience Australia. Canberra, ACT (3rd Edition, 2004).

GHD Pty Ltd (2014) *Natural Disaster Resilience Program Storm Tide Hazard Interpolation Study Report*. Report prepared for Department of Science, Information Technology, Innovation and the Arts.

Great Barrier Reef Marine Park Authority (GBRMPA) (2004) *Great Barrier Reef Marine Park Zoning Plan 2003*.

Great Barrier Reef Marine Park Authority (GBRMPA) (2019) *Great Barrier Reef Outlook Report 2019.* Townsville.

Groundwater Exploration Services Pty Ltd (GES) (2020) *Styx Core Test Data Results*. Letter dated 26 February 2020.

Groundwater Imaging (2019) *CQC Ogmore AgTEM Survey for Groundwater Investigation*. September 2019.

Gonfiantini, R. (1986) *Environmental Isotopes in Lake Studies*. In Fritz, P. and Fontes, J.C. *Handbook of Environmental Isotope Geochemistry*. Netherlands.

Hawkins, J.W. (1998) *Hydrogeologic Characteristics of Surface-Mine Spoil*. In Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania, ed. Brady, Smithy and Schueck. Harrisburg, Pennsylvania.

Horizon Soil Survey & Evaluation (2014) (Unpublished) *Report of Land Suitability Investigation Proposed Styx South Coal Project, Ogmore, Queensland*. Draft report prepared for Yeats Consulting Pty Ltd on behalf of Queensland Nickel and Fairway Coal.

Hvorslev, M.J. (1951) *Time Lag and Soil Permeability in Ground-Water Observations*. Bulletin No. 36, Waterways Exper. Sta. Corps of Engineers, U.S. Army, Vicksburg, Mississippi, pp. 1-50.

HydroSimulations (2014) *Baralaba North Continued Operations (BNCOP) Groundwater Modelling and Assessment*. Report HC2014/002, April 2014.

Intergovernmental Panel on Climate Change (IPCC) (2000) *Special Report on Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*. Nebojsa Nakicenovic and Rob Swart (Eds.) Cambridge University Press, UK. pp 570.

JBT (2012) *Report on Groundwater Seepage Studies and Operational Monitoring Review: Baralaba North Project. December 2012*.

Jones, C., Stanton, D., Hamer, N., Denner, S., Singh, K., Flook, S. and Dyring, M. (2019) *Field Investigation of Potential Terrestrial Groundwater-Dependent Ecosystems within Australia's Great Artesian Basin*. Hydrogeology Journal (2020) 28:237-261.

Jourde, H. Flodin, E.A., Aydin, A., Durlofsky, L.J., and Wen X.H. (2002) *Computing Permeability of Fault Zones in Eolian Sandstone from Outcrop Measurements*. AAPG Bulletin, Version 86, No.7, pp.1187-1200.

Kath, J. Reardon-Smith, K. Le Brocque, A. Dyer, F. and others (2014) Groundwater Decline and Tree Change in Floodplain Landscapes: Identifying Non-linear Threshold Responses in Canopy Condition. Global Ecol. Conserv. 2:148-160.

Kinnon, E.C. (2010) *Analysis of Gas and Water Production Pathways in Coal Seams*. Masters of Philosophy Thesis. The University of Queensland.

Lambeck, K. and Nakada, M. (1990) *Late Pleistocene and Holocene Sea-Level Change along the Australian Coast*. Palaeogeography, Palaeoclimatology, Palaeoecology 89(1-2): 143-176.

Levins, R. (1966) *The Strategy of Model Building in Population Biology*, American Scientist (54):421–431.

Lu, C. Werner, A.D., Simmons, C.T. and Luo, J. (2015) *A Correction on Coastal Heads for Groundwater Flow Models*. Groundwater Volume 53, No.1. pp. 164-170. January-February 2015.

Mackie, C.D. (2009) *Hydrogeological Characterisation of Coal Measures and Overview of Impacts of Coal Mining on Groundwater Systems in the Upper Hunter Valley of NSW*. Doctor of Philosophy Thesis. University of Technology, Sydney.

Malone, E. J. (1964) *1:250,000 Geological Series – Explanatory Notes: St Lawrence, Qld. Sheet SF/55-12 International Index*. Commonwealth of Australia and State of Queensland.

Maritime Safety Queensland (2019) *Queensland Tide Tables Standard Port Tide Times 2019*.

Matrix Plus (2012) *Groundwater Impact Assessment for Millennium Expansion Project Environmental Impact Statement*.

McNeil, V.H., Thames, D., Vaca, F., Bennett, L. and McGregor, G.B. (2018) *Regional Groundwater Chemistry Zones: Fitzroy-Capricorn-Curtis Coast and Burdekin-Haughton-Don Regions: Summary and Results. Draft for Consultation*. Water Planning Ecology, Department of Environment and Science, Queensland Government.

Melzer, A. Jaensch, R. and Cook, C. (2008) Landscape Condition in the Broadsound Basin: A Preliminary Assessment (2006 – 2007) to Guide Investment in Natural Resource Management. Centre for Environmental Management, Central Queensland University, Gladstone, Australia.

Merrick, D. (2017) *AlgoCompute: Large-Scale Calibration and Uncertainty Analysis Made Easy in the Cloud*. In Proc. MODFLOW and More, Golden, Colorado.

Miller, K.L., Berg, S.J., Davison, J.H., Sudicky, E.A., and Forsyth, P.A. (2018) *Efficient Uncertainty Quantification in Fully-Integrated Surface and Subsurface Hydrologic Simulations*. Advances in Water Resources, Volume 111, pp. 381-394.

Northcote, K. H. with Beckmann, G. G., Bettenay, E., Churchward, H. M., Van Dijk, D. C., Dimmock, G. M., Hubble, G. D., Isbell, R. F., McArthur, W. M., Murtha, G. G., Nicolls, K. D., Paton, T. R., Thompson, C. H., Webb, A. A. and Wright, M. J. (1960-1968). *Atlas of Australian Soils, Sheets 1 to 10*.

NTEC Environmental Technology (2011) *Groundwater Impact Assessment Bow Energy CSG Project*.

Office of Water Science (2020) *Water Tracers in Environmental Impact Assessments for Coal Seam Gas and Large Coal Mining Developments – Factsheet*. Prepared by the Office of Water Science for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development, Canberra.

O'Grady, E.P., Cook, P.G. and Fas, T. (2007) *A National Framework for Assessing the EWRs of GDEs – Report 2*. CSIRO Land and Water Australia.

Orange Environmental Pty Ltd (2020) *Central Queensland Coal Project Supplementary Environmental Impact Statement. Version 3. Chapter 16 - Matters of National Environmental Significance*.

Othman, R.S. (2003) *Petroleum Geology of the Gunnedah-Bowen-Surat Basins, Northern New South Wales – Stratigraphy, Organic Petrology and Organic Geochemistry*. A thesis submitted in fulfillment of the requirements for the degree of Doctor of Philosophy. Faculty of Science, University of New South Wales, July 2003.

Panday, S., Langevin, C.D., Niswonger, R.G., Ibaraki, M. and Hughes, J.D. (2013) MODFLOW-USG Version 1: *An UnStructured Grid Version of MODFLOW for Simulating Groundwater Flow and Tightly Coupled Processes Using a Control Volume Finite-Difference Formulation: United States Geological Survey Techniques and Methods*. Book 6, Chapter A45, 66p.

Panday, S. (2019) *USG-Transport Version 1.4.0: The Block-Centered Transport Process for MODFLOW USG.* GSI Environmental.

Paul, P.K, Zoback, M.D. and Hennings, P.H. (2009) *Fluid Flow in a Fractured Reservoir Using a Geomechanically Constrained Fault-Zone-Damage Model for Reservoir Simulation*. SPE Reservoir Evaluation & Engineering, Volume 12, Number 4, p. 562-575.

Rands, W.H. (1892) *Styx River Coalfield.* Geol. Surv. Qld Publ. 84, 1-10.

Rau, G.C., Acworth, R.I., Halloran, L.J.S., Timms, W.A., and Cuthbert, M.O. (2018) *Quantifying Compressible Groundwater Storage by Combining Cross-Hole Seismic Surveys and Head Response to Atmospheric Tides*. Journal of Geophysical Research – Earth Surface, Volume 123, Issue 8, pp. 1910-1930.

RGS (2020) *Technical Report. Geochemical Assessment of Waste Rock and Coal Reject. Central Queensland Coal Project*. Prepared for Orange Environmental Pty Ltd. Draft. 6 May 2020.

Reef Water Quality Protection Plan Secretariat (2009) *Reef Water Quality Protection Plan 2009*. September 2009.

Reef Water Quality Protection Plan Secretariat (2013a) *Reef Water Quality Protection Plan 2013*. July 2013.

Reef Water Quality Protection Plan Secretariat (2013b) *2013 Scientific Consensus Statement - Land Use Impacts on Great Barrier Reef Water Quality and Ecosystem Condition.* July 2013.

Shah, N., Nachabe, M. and Ross, M. (2007) *Extinction Depth and Evapotranspiration from Groundwater under Selected Land Covers*. Figure 4 in Groundwater Vol. 45. No. 3 May-June. pp. 329-338.

Shepherd, S.R. Leonard (1949) *Geological Survey Report – Bowman Coal Mine Styx River Coalfield CML No.227, Rockhampton*. 10 February 1949. Queensland Government Mining Journal, 20 May 1949.

SKM (2014) *Baralaba North Continued Operations Project Environmental Impact Statement Groundwater Studies – Preliminary Conceptual Groundwater Model*. February 2014.

State of Queensland (2017) *Terms of Reference for the Environmental Impact Statement for the Central Queensland Coal Project*. August 2017.

State of Queensland and Commonwealth of Australia (2003) *Reef Water Quality Protection Plan 2003*.

Styx Coal Pty Ltd and Fairway Coal Pty Ltd (2016) *Styx Coal and Fairway Coal Styx Coal Project EPBC Referral*. December 2016. Referral information prepared by CDM Smith.

Theis, C.V. (1935) *The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage*. Am. Geophys. Union Trans., Vol. 16, pp. 519-524.

URS (2009) *Caval Ridge Groundwater Impact Assessment*. BMA Coal Operations Pty Ltd.

URS (2012) *Arrow Bowen Gas Project Environmental Impact Statement*.

Vekta Pty Ltd (2011) *Styx Coal Mine Project Report – Yeats Consulting Engineers*. 13 September 2011.

Verruijt, A. (1968) *A Note on the Ghyben-Herzberg Formula*. Bulletin of the International Association of Scientific Hydrology, XIII, 4-12. Technological University, Delft, The Netherlands.

Walkom A.B. (1919) *Mesozoic Floras of Queensland. Part III and IV: The Floras of the Burrum and Styx River Series*. Geol. Surv. Qld Publ., 263, 7-78.

Waterhouse, J., Schaffelke, B., Bartley, R., Eberhard, R., Brodie, J., Star, M., Thorburn, P., Rolfe, J., Ronan, M., Taylor, B., and Kroon, F. (2017). *2017 Scientific Consensus Statement – Land Use Impacts on Great Barrier Reef Water Quality and Ecosystem Condition*. Independent Science Panel: Shaw, R., Abal, E., Grundy, M., Doherty, P., Yorkston, H., Bonnett, G., Ash, A., Stauber, J. and Harc, B.

Wilson, P.R. and Taylor, P.M. (2012) *Land Zones of Queensland*. Queensland Herbarium, Queensland Department of Science, Information Technology, Innovation and the Arts, Brisbane. 79 pp.

Withnall I.W., Hutton L.J., Bultitude R.J., von Gnielinski, F.E. and Rienks I.P. (2009) *Queensland Geology 12: Geology of the Auburn Arch, Southern Connors Arch and Adjacent Parts of the Bowen Basin and Yarrol Province, Central Queensland*. Geological Survey of Qld.

WRM Water & Environment Pty Ltd (2020) *Flood Study and Site Water Balance Technical Report. Central Queensland Coal Project. 1596-01-E*-Draft, 15 May 2020.

Xenith Consulting (2020) *Central Queensland Coal Progressive Rehabilitation*. 10 Slide Presentation. April 2020.

Yeats Consulting (2012) *Report for Styx Coal South Project EM Plan Stygofauna Survey*. July 2012.

Yeats Consulting Engineers (2012) *Preliminary Surface Water Resources Technical Report. Styx Coal Project, Styx Basin, Qld*. April 2012.

3D Environmental (2020) *Field Studies of Type 3 Groundwater Dependent Ecosystems. Central Queensland Coal Project.* Prepared on behalf of Eco Logical Australia Pty Ltd, Orange Environmental Pty Ltd and CQCPL.

14.0 ABBREVIATIONS AND ACRONYMS

ACARP	Australian Coal Association Research Program
ACT	Australian Capital Territory
ADWG	Australian Drinking Water Guidelines
AEP	Annual Exceedance Probability
AGE Consultants	Australasian Groundwater and Environmental Consultants
AGMG	Australian Groundwater Modelling Guidelines
AHD	Australian Height Datum
AIMS	Australian Institute of Marine Science
Al	Aluminium
AMEC	Australian Mining Engineering Consultants
AMSL	Australian Mean Sea Level
ANC	Acid Neutralising Capacity
ANSTO	Australian Nuclear Science and Technology Organisation
ANZECC	Australian and New Zealand Environment and Conservation Council
ANZG	Australian and New Zealand Guidelines
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
As	Arsenic
ASRIS	Australian Soil Resource Information System
ASS	Acid Sulfate Soils
ATS	Adaptive Time Stepping
AWBM	Australian Water Balance Model
AWQG	Australian Water Quality Guidelines
AWS	Automatic Weather Station
B	Boron
BFI	Base Flow Index
BHWE	Base Horizon of Weathering
BOM	Bureau of Meteorology
BPEast	Borrow Pit East
CCiA	Climate Change in Australia
Cd	Cadmium
CDFM	Cumulative Departure from Mean
CEC	Cation Exchange Capacity
CHD	Constant Head
CHPP	Coal Handling and Preparation Plant
Co	Cobalt

CQC	Central Queensland Coal
CQCPL	Central Queensland Coal Pty Ltd
CSG	Coal Seam Gas
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Cr	Chromium
Cu	Copper
CVFD	Control Volume Finite Difference
DAF	Department of Agriculture and Fisheries
DAFF	Department of Agriculture, Fisheries and Forestry
DAWE	Department of Agriculture, Water and the Environment
DEE	Department of the Environment and Energy
DEHP	Department of Environment and Heritage Protection
DEM	Digital Elevation Model
DES	Department of Environment and Science
DIN	Dissolved Inorganic Nitrogen
DIWA	Directory of Important Wetlands in Australia
DNRM	Department of Natural Resources and Mines
DNRME	Department of Natural Resources, Mines and Energy
DNRMW	Department of Natural Resources, Mines and Water
^{o}C	Degrees Celsius
DO	Dissolved Oxygen
DotE	Department of the Environment
DSDIP	Department of State Development, Infrastructure and Planning
DSITI	Department of Science, Information Technology and Innovation
DSITIA	Department of Science, Information Technology, Innovation and Arts
EA	Environmental Authority
EC	Electrical Conductivity
EIS	Environmental Impact Statement
ELVIS	Elevation Information System
ENSO	*El Nino* Southern Oscillation
EP Act	*Environmental Protection Act 1994* (Qld)
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth)
EPC	Exploration Permit for Coal
EPM	Exploration for Permits for Minerals other than Coal
EPP	Exploration Permit for Petroleum
ERA	Environmentally Relevant Activity
ESD	Ecologically Sustainable Development

ESP	Exchangeable Sodium Percentage
ET	Evapotranspiration
EV	Environmental Value
F	Fluoride
FBA	Fitzroy Basin Association Inc.
FCPL	Fairway Coal Pty Ltd
Fe	Iron
FHA	Fish Habitat Area
ft	foot
GAB	Great Artesian Basin
GAI	Geochemical Abundance Index
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
GDE	Groundwater Dependent Ecosystem
GDEMMP	Groundwater Dependent Ecosystem Management and Monitoring Plan
GES	Groundwater Exploration Services Pty Ltd
GL/annum	Gigalitres per annum
gm/cc	grams per cubic centimetre
GMWL	Global Meteoric Water Line
H	Hydrogen
H.A.T.	Highest Astronomical Tide
HES	High Ecological Significance
HGSUQ	HydroGeoSphere Uncertainty Quantification
HGTC	High Grade Thermal Coal
IESC	Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development
Inc.	Incorporated
IPCC	Intergovernmental Panel on Climate Change
IPO	Interdecadal Pacific Oscillation
K_H	Horizontal Hydraulic Conductivity
km	Kilometres
K_b	Recession Constant
K_V	Vertical Hydraulic Conductivity
Lat.	Latitude
LGA	Local Government Area
LHS	Latin Hypercube Sampling

LiDAR	Light Detection and Ranging
LMWL	Local Meteoric Water Line
Long.	Longitude
LOR	Limit of Reporting
LPF	Layer Property Flow
LWP	Leaf Water Potential
m	metre
mAHD	metres Australian Height Datum
mbgl	metres below ground level
Mbcm	Million bulk cubic metres
mbTOC	metres below Top of Casing
MDL	Mineral Development Licence
mg/L	milligrams per Litre
MIA	Mine Industrial Area
ML	Megalitres
ML [No.]	Mining Lease
ML/day	Megalitres per day
mm	millimetre
Mn	Manganese
MNES	Matters of National Environmental Significance
MNP	Marine National Park
Mo	Molybdenum
MPA	Maximum Potential Acidity
MPa	Megapascal
µS/cm	MicroSiemens per Centimetre
Mtpa	Million Tonnes per Annum
NAPP	Net Acid Producing Potential
NDRP	Natural Disaster Resilience Program
Ni	Nickel
N.L.	No Liability
NSW	New South Wales
NTU	Nephelometric Turbidity Units
NWC	National Water Commission
O	Oxygen
OGIA	Office of Groundwater Impact Assessment
OWS	Office of Water Science
PAF	Potentially Acid Forming

Pb	Lead
PEST	Parameter Estimation Software
PSM	Permanent Survey Marker
Qa	Quaternary Alluvium
Qpa	Quaternary Pleistocene Alluvium
Qld	Queensland
RCH	Recharge
RCP	Representative Concentration Pathways
Reef 2050 WQIP	Reef 2050 Water Quality Improvement Plan
REMP	Receiving Environment Monitoring Program
Rn	Radon
ROM	Run-of-Mine
SDPWO Act	*State Development and Public Works Organisation Act 1971* (Qld)
Se	Selenium
SEIS	Supplementary Environmental Impact Statement
SILO	Scientific Information for Land Owners
SMS	Sparse Matrix Solver
SRES	Special Report of Emissions Scenarios
SRMS	Scaled Root Mean Square
SRTM	Shuttle Radar Topography Mission
S_s	Specific Storage (Storativity)
SSCC	Semi-soft Coking Coal
SWL	Standing Water Level
S_y	Specific Yield
T	Transmissivity
TDS	Total Dissolved Solids
TEM	Transient Electromagnetic
this Report	Numerical Groundwater Model and Groundwater Assessment Report for the Central Queensland Coal Project Supplementary EIS Version 3 – Responses to Submissions
TLO	Train Load Out
TN	Total Nitrogen
TOC	Top of Casing
TOR	Terms of Reference
TP	Total Phosphorus
TSS	Total Suspended Solids
U	Uranium

UWIRs	Underground Water Impact Reports
Underground Water Management Act	*Environmental Protection (Underground Water Management) and Other Legislation Amendment Act 2016*
USG	UnStructured Grid
V	Vanadium
WaTERS	Water Tracking and Electronic Reporting System
WBG	Walton Bore Geophysics
WPA	Wetland Protection Area
WQO	Water Quality Objective
WROLA	*Water Reform and Other Legislation Amendment Act 2014*
WRP	Water Resource Plan
Zn	Zinc

ATTACHMENT 1
GOVERNMENT SUBMISSIONS AND IESC ADVICE RECONCILIATION TABLES

Table A1-1
Summary of Department of Agriculture and Fisheries (DAF) Submission Comments [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
1	DAFF [1.1a]	*The drop in base flows to Tooloombah Creek and Deep Creek will cause the loss of permanent and ephemeral pools. …*	**The model predicted volumetric differential in groundwater baseflow contributions and/or enhanced leakage in Tooloombah Creek and Deep Creek have been determined based on the improved numerical groundwater model. The corresponding volumetric changes in stream flow (and interflow) frequency and pool persistence, and consequential impacts on riparian vegetation and aquatic ecosystems is assessed separately by WRM Water & Environment (2020) and Eco Logical Australia Pty Ltd (2020), respectively.** Based on all the available groundwater datasets, the inferred depth to groundwater table is presented in **Figure 5-4**. Beyond the banks of the deep-cut and incised watercourses, the depth to groundwater in lower lying topographic areas and shallow drainages are typically greater than 8-10 m. **Section 7.7.6** (**Table 7-17**) presents the model estimated (groundwater) baseflow / leakage for select reaches of Deep Creek, Tooloombah Creek and Styx River in the vicinity of and downstream of the CQC Project. As demonstrated by the January-February 2020 rainfall events and flow gauging datasets (including survey levels and continuous datalogger results) (**Section 3.3**), the Tooloombah Creek pool level may be controlled by the downstream rock bar resulting in surface water levels being pooled/dammed above the groundwater table (and therefore such interflow recharging the Quaternary (Holocene) Alluvium and Regolith) following rainfall periods. Relevantly, as described in **Section 6.1.2**, the piezometric pressure head / elevation in the lower stratigraphy of the Styx Coal Measures at WMP06 (16.9 mAHD) where it subcrops in the west, and near the pinch / saddle point downstream of the Mamelon Creek and Tooloombah Creek confluence (to the west), Mt Brunswick and Mt Mamelon, and sub-catchment tributary of Tooloombah Creek, is equivalent to the recorded groundwater levels recorded approximately 2.5 km downstream at WMP04. The invert of Deep Creek was observed as being dry during the extended below average rainfall conditions. Predicted changes in baseflow (i.e. reduced contributions / enhanced leakage) in Tooloombah Creek and Deep Creek have been modelled and are presented in **Section 8.6**. The Model Predicted Flux – Indirect Baseflow Changes / Enhanced Leakage During and Post-Mining are shown on **Graph 8-3**, and comparison of specific reaches on Tooloombah Creek provided on **Graph 8-4**. The quantitative Uncertainty Analysis is presented in **Section 8.11.2** and key aggregate metrics are presented in **Table 8-8** to provide an indication of the magnitude of differences for the changes in baseflow / enhanced leakage estimates, and corresponding probabilities. Photographic plates and previous stream mapping information to demonstrate the nature of watercourses and drainage lines across the site are presented in **Section 3.3**, including Tooloombah Creek and Deep Creek subject to potential/predicted effects of groundwater drawdown. Other potential influences including tidal fluctuations, storm tides, flood extents and sea level rise have also been considered. The diffuse / indirect baseflow changes have also been contextualised separately by WRM Water & Environment (2020) with predicted changes in the reporting catchment resulting from the progressive development of the CQC Project.

Table A1-1 (Continued)
Summary of Department of Agriculture and Fisheries (DAF) Submission Comments [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
2	DAFF [1.1b]	*It is uncertain if supplementary water inputs would be sufficient to maintain this system and if this mechanism is able to be continued until the mines impacts cease. …*	**Negligible changes in natural baseflow to and/or leakage from surface water systems, as a consequence of predicted reductions in potentiometric head and temporal drawdown in the near vicinity of the open cut mining operation, with model predicted volumetric differentials in baseflow to and/or enhanced leakage considered separately by Eco Logical Australia Pty Ltd (2020a; 2020d), including the changes in reporting catchment resulting from the progressive development of the CQC Project presented by WRM Water & Environment (2020).** No supplementary water inputs are proposed by CQCPL for the CQC Project, therefore do not require consideration for future groundwater model validation (i.e. as a potential future input to streamflow). However, it is noted that controlled water releases may occur as outlined in WRM Water & Environment Pty Ltd (2020). Record-keeping of such additional water volumes/inputs would be important to inform future groundwater model validation and is relevantly noted as a component of the REMP. Importantly it is also noted that piezometric pressure heads in the Back Creek Group (generally of lesser salinity than Styx Coal Measures) which subcrop to the west and upstream of the CQC Project between Mt Brunswick and Mt Mamelon are predicted to be maintained and thus potentially dampen any potential effects of localised drawdown in the sub-cropping Styx Coal Measures, should drier conditions be experienced during the Project life (and post-mining) and stream flow, interflow and pool levels substantially reduce naturally for periods in Tooloombah Creek.
3	DAFF [1.1c]	*The impacts of the reduction in base flows in the estuarine areas connected to these systems has not been quantified. … The drawdown causing the mobilisation of the groundwater-saltwater interface is of particular concern as it can potentially negatively impact large areas of brackish and freshwater fish habitats as well as the Broad Sound Declared Fish Habitat Area. This impact is likely to be expressed to the greatest extent, a decade or more post the closure of the mine.*	**The extent of predicted drawdown, and corresponding model estimated (quantified) changes in volume of base flows (including leakage) in areas adjacent to and downstream of the CQC Project demonstrates that the reductions would be negligible and indiscernible including the connected (downstream) estuarine areas. For example, the model predicted peak difference in the annualised flows from the Broad Sound Fish Habitat Area as a result of the CQC Project is <0.002 ML/year.** As shown on **Graphs 8-3 and 8-4**, the residual differences for Broad Sound Declared Fish Habitat Area, Styx River and downstream Tooloombah Creek reach (below the Deep Creek confluence) asymptote to zero post closure of the mine. In terms of the hypothesised potential mobilisation of the groundwater-saltwater interface, as presented in **Section 8.5.1**, the predicted groundwater drawdown (0.5 m contour) influence in the Styx Coal Measures as a result of the CQC Project do not extend as far as the historic Ogmore mine workings (some 8 km downstream) to result in any superposition effects, and therefore is not expected to result in any discernible change to the location of the freshwater-saltwater interface. That is, even if the interface was to be transient (or static) north of the historic Ogmore workings, there would not be expected to be any change. It is important to note that the tidal boundary condition applied at the Broad Sound Fish Habitat Area has also been tested as a component of the Uncertainty Analysis and the results discussed in **Section 8.11.3**.
4	DAFF [1.2]	*Provide an assessment of the impacts on this MSES [FHA-047 – Broad Sound Declared Fish Habitat Area] including the impacts of the movement of the saltwater interface post mine closure until an equilibrium state is attained.*	**Refer to Response to DAFF [1.1c]. Section 6.3.2 also relevantly describes the broad conceptualisation used (Ghyben-Herzberg Relationship) for deriving the freshwater-saline water interface.** As described in **Section 7.1.2 (Table 7-1)**, improvements to the numerical groundwater model included extension of the model domain to include a greater portion of the Broad Sound Declared Fish Habitat Area (FHA-047) and additional areas of FHA-047 in the Wellington Creek (including Stoodleigh Creek) Catchments. Refinement of the model grid (unstructured) along watercourses, drainage features and wetlands for groundwater connectivity analysis was also completed.

Table A1-1 (Continued)
Summary of Department of Agriculture and Fisheries (DAF) Submission Comments [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
5	DAFF [1.3]	… *correct the figure to include the Broad Sound Declared Fish Habitat Area (map attached).*	**Refer to Figure 3-5**. The improved numerical groundwater model mesh has been refined to allow for clarification of predicted changes at the extents of the Broad Sound Declared Fish Habitat Area (FHA-047).
6	DAFF [1.4]	*Include clearer description of the application of Accepted development requirements for operational work that is constructing or raising waterway barrier works and SDAP State Code 18 in areas outside the mining lease. Include Accepted development requirements for operational work that is constructing or raising waterway barrier works as a guide to best practice within the mining lease.*	**Not a Groundwater-Related Matter.**
7	DAFF [1.5]	*It is appropriate to offset the area of Tooloombah Creek and Deep Creek upstream of their junction, as there are Significant Residual Impacts. …*	As noted in **Section 11.2**, an assessment of significant residual impacts is undertaken separately by Orange Environmental (2020) and offsets by others, with relevant input from Eco Logical Australia Pty Ltd (2020a). **Refer to Response to DAFF [1.1b and 1.1c].** Reaches of the Tooloombah Creek and Deep Creek watercourses are as mapped and defined in the *Water Act, 2000* and have been consistently applied in the improved numerical groundwater model. For the purposes of refined analysis (during and post-mining) (**Sections 8.6 and 8.9**), Tooloombah Creek has been partitioned into three reaches (1-3) and Deep Creek into two reaches (1-2) as follows (**Table 7-17**): 1) Tooloombah Creek Reach 1 - Downstream of the junction with Deep Creek to the named Styx River. 2) Tooloombah Creek Reach 2 - Upstream of the junction with Deep Creek and adjacent the CQC Project to Mamelon Creek. 3) Tooloombah Creek Reach 3 - Upstream of Mamelon Creek confluence. 4) Deep Creek Reach 1 – Upstream of the junction with Tooloombah Creek and adjacent the CQC Project to Brussels Creek. 5) Deep Creek Reach 2 – Upstream of the Brussels Creek confluence.
8	DAFF [1.6]	*Provide modelling of the seawater — freshwater interface at relevant intervals for the predicted duration of impacts.*	The broad conceptualisation for the freshwater-saltwater interface position is described in **Section 6.3.2**. Considering the inferred groundwater level (phreatic surface) further inland near the Tooloombah Creek and Deep Creek confluence (north of the CQC Project) is up to 10 m (i.e. $h_f = 7$ m), it would then equate to a 280 m interface depth. Furthermore, noting that the SWL at the deepest northern extent of the proposed open cut is in the order to 15-20 mAHD (**Figure 5-3**), it would then equate to a 480-680 m interface depth. For relative comparison, the bottom of the proposed open cut at the deepest point is at approximately -152mAHD. However, it is relevantly noted that this conceptualisation assumes the density of freshwater is maintained inland and it is known the Cenozoic sediments tend to be more saline (**Section 5.5.2**) so conservatively applying a reduced (half) α factor (where $\rho_f > 1$ gm/cc) would still result in an interface being at 240-340 m; approximately 100 m below the bottom of the proposed open cut. It is recognised that there are many other factors which effect the interface location including topography, geology architecture (geometry), recharge, vegetation cover as well as historic anthropogenic use. Each of these factors are considered by the improved numerical groundwater flow model. *[Cont. Over Page]*

Table A1-1 (Continued)
Summary of Department of Agriculture and Fisheries (DAF) Submission Comments [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
8	*[As Above, Cont.]*	*[As Above, Cont.]*	Laterally, the predicted groundwater drawdown (0.5 m contour) influence in the Styx Coal Measures as a result of the CQC Project do not extend as far as the historic Ogmore mine workings (some 8 km downstream) to result in any superposition effects, and therefore is not expected to result in any discernible change to the location of the freshwater-saltwater interface (nearer to the surface). That is, even if the interface was to be transient (or static) north of the historic Ogmore workings, there would not be expected to be any change. Despite the above conclusions based on the broad conceptualisation, scenario based sensitivity analysis has been undertaken as part of the uncertainty analysis (**Section 8.11.3**) to investigate low (2 mAHD) and high (4.5 mAHD) constant head (seawater) boundary conditions and, complemented with use of USG-Transport software, modelled the differences. As shown on **Figures 8-7[a] and 8-7[b]**, the differences in maximum predicted groundwater drawdown in Layers 2 and 8 are negligible despite there being a 2.5 m differential in the fixed head boundary condition. Thus, changes to the inferred freshwater-seawater interface based on the broad conceptualisation would be indiscernible.
9	DAFF [1.7]	*The greatest drawdown impacts are post mine closure. There are no indicators of ongoing mitigation… Thus if the project were to proceed, indication of mitigation for the predicted duration of the impacts and in addition offsets, will be required for all predicted impacted streams. Provide evidence of the suitability of supplementary watering on the base geology of the Styx Basin or similar.* *…* *Greater evidence is needed of the efficacy of the supplementary environmental flows in maintaining natural flow patterns.*	Model layer head plots during and post-mining are presented in **Attachment 15. Refer to Response to DAFF [1.1a, 1.1b, 1.1c and 1.5].** Nevertheless, ongoing monitoring, management and mitigation measures for the duration of the operations are described in **Section 10.0** which allow for adaptive / contingent measures (if required, albeit unlikely) to be developed in advance of potentially greater drawdown. **Importantly it is also noted that piezometric pressure heads in the Back Creek Group (generally of lesser salinity than Styx Coal Measures) which subcrop to the west and upstream of the CQC Project between Mt Brunswick and Mt Mamelon are predicted to be maintained and thus potentially dampen any potential effects of localised drawdown in the subcropping Styx Coal Measures, should drier conditions be experienced during the Project life (and post-mining) and stream flow, interflow and pool levels substantially reduce naturally for periods in Tooloombah Creek.** It is also noted that the improved numerical groundwater model results are presented for the transient prediction and transient recovery model variants in **Section 8.0**. No supplementary water inputs are proposed by CQCPL for the CQC Project, therefore do not require consideration for future groundwater model validation (i.e. as a potential future input to streamflow). However, it is noted that controlled water releases may occur as outlined in WRM Water & Environment Pty Ltd (2020). Record-keeping of such additional water volumes/inputs would be important to inform future groundwater model validation and is relevantly noted as a component of the REMP.
10	DAFF [1.8]	*The re-establishment of fish passage at the closure of mining will have little meaning, if the ongoing loss of habitat and upstream pools in Tooloombah and Deep Creeks removes the habitat.*	**Refer to Response to DAFF [1.1a, 1.1b, 1.1c, 1.2, 1.5 and 1.7].** Refer also to separate assessments by WRM Water & Environment (2020) and Eco Logical Australia (2020a).
11	DAFF [1.9]	*Offset areas.*	**Refer to Response to DAFF 1.5.** An assessment of significant residual impacts is undertaken separately by Orange Environmental (2020) and offsets by others, with relevant input from Eco Logical Australia Pty Ltd (2020a).

Table A1-1 (Continued)
Summary of Department of Agriculture and Fisheries (DAF) Submission Comments [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
12	DAFF [1.10]	*Offset waterways providing fish passage as financial offset.*	**Refer to Response to DAFF [1.9].**
13	DAFF [1.11]	*Include the Broad Sound Declared Fish Habitat Area (FHA) in calculations of offsets and impact assessments.*	**Refer to Response to DAFF [1.2 and 1.9].**
14	DAFF [1.12]	*Create condition to meet the requirement for the maintenance of base flow within Tooloombah and Deep creeks.*	**Refer to Response to DAFF [1.1a, 1.1b and 1.1c].** No supplementary water inputs are proposed by CQCPL for the CQC Project, therefore do not require consideration for future groundwater model validation (i.e. as a potential future input to streamflow). However, it is noted that controlled water releases may occur as outlined in WRM Water & Environment Pty Ltd (2020). Record-keeping of such additional water volumes/inputs would be important to inform future groundwater model validation and is relevantly noted as a component of the REMP.
15	DAFF [1.13]	*The roughening of the culvert base is required unless the culvert base is buried. The base to be a minimum of 300mm below bed level and allow natural material to deposit on the culvert base.*	**Not a Groundwater-Related Matter.**
16	DAFF [1.14]	*The figures included below are marked to show areas of waterway that are not considered to offer fish habitat and offsets to be calculated based on this advice.*	**Noted. Not a Groundwater-Related Matter.**

Table A1-2

Summary of Department of Environment and Science (DES) Submission Comments – Updated August 2019 [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
17	DES [1/32.1a]	*There is very limited available groundwater (GW) data, including GW levels, historical trends, the historical behaviour of GW levels and potential connectivity to surface water flow.*	**Refer to Section 5.0 which presents the groundwater datasets and describes the dependent assets (including groundwater connectivity and dependency).** The groundwater monitoring network installed within ML 80187, ML 700022 and surrounds is extensive and has been progressively developed as part of initial exploration and groundwater investigation programs (i.e. 2010-11, 2011-12 and 2014), through to targeted and detailed groundwater investigations, bore census and baseline monitoring network installations (and extensions) in 2017 and 2018, and supplementary groundwater investigations and continued baseline groundwater monitoring in 2019 to support improvements to the groundwater modelling and assessments and future validation, including more recently: • continued monthly baseline groundwater level monitoring (and groundwater sampling for quality analysis) at the 2017 WMP Series (WMP02, WMP04, WMP04D, WMP05, WMP06, WMP07, WMP08, WMP08D, WMP09, WMP10, WMP11, WMP11D, WMP12, WMP13, WMP14, WMP15); • establishment of ongoing periodic (e.g. monthly) baseline groundwater level monitoring (and groundwater sampling for analysis) at the 2018 WMP Series (WMP15, WMP16D, WMP17, WMP17D, WMP18, WMP18D, WMP19, WMP19D, WMP20, WMP20D, WMP21, WMP22A, WMP22B, WMP22C, WMP23A, WMP24, WMP25, WMP26, WMP27, WMP28, WMP29A, WMP29B, WMP29C, WMP29D, WMP29E, WMP30A, WMP30B, WMP30C); • continued monthly baseline groundwater level monitoring (and groundwater sampling for quality analysis) at select landholder bores (BH01X and BH16); • regular (generally every 2nd day) on-site groundwater level recordings (and field groundwater quality testing) in select WMP Series (WMP04, WMP10, WMP22A, WMP24), exploration drill hole (STX1205L) and select waterholes / pools on Tooloombah Creek (Easting 772174; Northing 7489156) and Deep Creek 1 (Easting 774721; Northing 7485632) and Deep Creek 2 (Easting 775987; Northing 7485672) undertaken as part of the AMEC (2019) groundwater investigation; • continuous datalogging of alluvial groundwater levels in groundwater bores responsive to stream or flood recharge in Deep Creek (WMP05) [paired with new Gauging Station No. 330452], Tooloombah Creek (WMP04) [paired with new Gauging Station No. 330451] and the Styx River (WMP29A) [for comparison with Broad Sound tides and local observations at Ogmore Road Bridge crossing]; and • installation of a new VWP (WMP31) targeting the basement aquifers to the north-east (and east of the regional fault) targeting the Styx Coal Measures basement (i.e. Permian Measures – Back Creek Group). In addition to the above, several additional site-specific groundwater investigations have been undertaken in 2019 to support the groundwater monitoring datasets including: • transient electromagnetic (TEM) survey of groundwater associated with surficial geology (Groundwater Imaging, 2019) (**Attachment 5**); • open end permeability and packer testing at two exploration drill holes STX1901 and STX1902 (AMEC, 2019) (**Attachment 7**); and • core sampling from two exploration drill holes STX1812 and STX1903 and laboratory permeability testing (GES, 2020) (**Attachment 9**).

Table A1-2 (Continued)
Summary of Department of Environment and Science (DES) Submission Comments – Updated August 2019 [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
17	*[As Above, Cont.]*	*[As Above, Cont.]*	**Section 3.1.1 describes the historical rainfall trends (including cumulative deviation from the mean), which is presented on the calibration hydrographs (Attachment 8) along with the history-matching of the improved numerical groundwater model results based on historic mining and investigations presented in Section 7.5.6. Modelled groundwater connectivity with watercourses are also discussed in Sections 7.5.3 and 7.7.6, considering the available hydrological datasets presented in Section 3.3.** As shown in **Graph 7-3**, calibration datasets were extended and the long term historical below average rainfall trends can be observed in the model outputs as well as more recently (2018-2019) (**Attachment 8**) with changes in groundwater levels corresponding with below average rainfall periods around the 1960s, 2000s and approaching 2020.
18	DES [1/32.1b]	*Provide additional detailed information on how potential impacts on flow regimes (and recharge) are to be measured, monitored and conditioned.*	**The proposed groundwater monitoring program is detailed in Section 10.1, with groundwater level and groundwater quality triggers described in Sections 10.1.10 and 10.1.11. The corresponding draft EA Conditions are presented in Section 10.10.** **Also refer to Response to DAFF [1.1a]**. The predicted changes in groundwater baseflow contributions and/or enhanced leakage in Tooloombah Creek and Deep Creek have been determined based on the improved numerical groundwater model. The corresponding volumetric changes in stream flow (and interflow) frequency and pool persistence, and consequential impacts on riparian vegetation and aquatic ecosystems is assessed separately by WRM Water & Environment and Eco Logical Australia, respectively. Thus, surface water, stream health (aquatic) and riparian vegetation monitoring are described separately by WRM Water & Environment and Eco Logical Australia. In relation to recharge, it is noted that enhanced recharge has been applied across the backfill waste rock emplacement areas using the TVM properties in the improved numerical groundwater model. Validation monitoring of enhanced recharge in such areas can be monitored by the recovery of groundwater levels in monitoring standpipes in the vicinity of backfill spoil areas, particularly in the north (west of the fault) during the operations. As such it is recommended that the existing (shallow) and additional northern (deep) monitoring standpipes be retained to monitor the recovery levels in the Pleistocene Alluvium / Regolith and Styx Coal Measures (**Section 10.1.7**).
19	DES [1/32.1c]	*Provide further detailed analysis of the alluvium and Styx Coal measure overburden groundwater levels as they relate to groundwater interactions.*	**Refer to Sections 4.2, 4.3, 5.1.1, 5.1.2, 5.2, 5.3 and 5.4 for a detailed analysis of outcrop and surficial geology, including alluvium and Styx Coal Measures, and groundwater monitoring and investigations including TEM survey, fluvial geomorphology assessment (historical deposition processes) and targeted investigation (packer testing & constant head tests) (Section 5.6) / groundwater monitoring in 2019 to expand existing datasets (including contemporary database searches and bore survey).** Additional stream flow gauging and corresponding datalogging in nearby alluvium bores (WMP04, WMP05 and WMP29A) is also presented in **Section 3.3**. **Section 6.3.3** describes the baseline conditions for the conceptual groundwater model which informed the improved numerical groundwater model, with modelled groundwater connectivity with watercourses discussed in **Sections 7.5.3 and 7.7.6**, considering the available hydrological datasets presented in **Section 3.3**.

Table A1-2 (Continued)
Summary of Department of Environment and Science (DES) Submission Comments – Updated August 2019 [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
20	DES [1/32.1d]	*Discussion on the post-closure water quality in relation to the Styx River, Shoalwater Creek and Water Park Creek Basins Environmental Values and Water Quality Objectives (DEHP 2014) is required. Detail the post-closure operation and maintenance of the abstraction bores and related supplementary water infrastructure.* *Provide additional information on the suitability of supplementary watering by GDE type with reference to site characteristics and the expected life of groundwater drawdown impact.* *Provide additional information on the feasibility of indirect application of supplementary water to Type 3 GDEs given site characteristics (e.g. steep incised stream banks).* *Describe the potential risks/impacts of site specific direct application approaches.*	**Refer to Section 6.2. Whilst reference is made to the Styx River, Shoalwater Creek and Water Park Creek Basins Environmental Values and Water Quality Objectives (DEHP, 2014a), it is noted that the Qld Government published draft consultation materials (including revised EVs, WQOs and aquatic ecosystem protection mapping) for the Fitzroy-Capricorn-Curtis Coast Region Groundwaters in early 2019, with the consultation submission closing date on 1 March 2019.** Therefore, water quality objectives (WQOs) and corresponding triggers and draft EA conditions have been discussed considering both the DEHP (2014a) WQOs, and potential future WQOs in **Section 10.10**. Predicted changes in baseflow (i.e. reduced contributions / enhanced leakage) in Tooloombah Creek and Deep Creek have been modelled and are presented in **Section 8.6**. As shown on **Graphs 8-3 and 8-4**, the residual differences for Broad Sound Declared Fish Habitat Area, Styx River and downstream Tooloombah Creek reach (below the Deep Creek confluence) asymptote to zero post closure of the mine. **Also refer to Response to DAFF [1.1a].** The predicted changes in groundwater baseflow contributions and/or enhanced leakage in Tooloombah Creek and Deep Creek have been determined based on the improved numerical groundwater model. The corresponding volumetric changes in stream flow (and interflow) frequency and pool persistence, and consequential impacts on riparian vegetation and aquatic ecosystems is assessed separately by WRM Water & Environment (2020) and Eco Logical Australia (2020a), respectively. No supplementary water inputs are proposed by CQCPL for the CQC Project, therefore do not require consideration for future groundwater model validation (i.e. as a potential future input to streamflow). However, it is noted that controlled water releases may occur as outlined in WRM Water & Environment Pty Ltd (2020). Record-keeping of such additional water volumes/inputs would be important to inform future groundwater model validation and is relevantly noted as a component of the REMP.
21	DES [1/32.1e]	*The Department identified significant uncertainties associated with the proposed project, including a seasonal understanding of water levels and quality. Remodelling would also be required to predict potential impacts of the groundwater drawdown.*	**Section 3.1.1 describes the historical rainfall trends (including cumulative deviation from the mean), which is presented on the calibration hydrographs (Attachment 8) along with the history-matching of the improved numerical groundwater model results based on historic mining and investigations presented in Section 7.5.6. Modelled groundwater connectivity with watercourses are also discussed in Sections 7.5.3 and 7.7.6, considering the available hydrological datasets presented in Section 3.3.** As shown in **Graph 7-3**, calibration datasets were extended and the long term historical below average rainfall trends can be observed in the model outputs as well as more recently (2018-2019) (**Attachment 8**) with changes in groundwater levels corresponding with below average rainfall periods around the 1960s, 2000s and approaching 2020. Additional stream flow gauging and corresponding datalogging in nearby alluvium bores (WMP04, WMP05 and WMP29A) is also presented in **Section 3.3**. Relevantly, given the recent extended period of dry (and no flow) conditions recorded in many of the local drainages as well as pools which had since dried from mid-2019 in Deep Creek and pool levels receding in Tooloombah Creek (with increasing salinity reflecting potentially evapo-concentration effects and/or groundwater inputs), rainfall runoff is demonstrably likely to be the primary source of stream flow across the CQC Project area.

Table A1-2 (Continued)
Summary of Department of Environment and Science (DES) Submission Comments – Updated August 2019 [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
21	*[As Above, Cont.]*	*[As Above, Cont.]*	Surface water and groundwater quality datasets are presented in **Sections 3.2.7 and 5.5**, as well as a description of tidal influence in **Section 3.3**. Based on the available datasets, the groundwater quality for the hydrogeological units, relevant WQOs and conceptualisation, considering the freshwater-saline water interface is discussed in **Sections 6.1, 6.2 and 6.3**.
22	DES [1/32.1f]	*Remodelling would also be required to predict potential impacts of the groundwater drawdown.*	Remodelling has been undertaken based on the updated conceptualisation (**Section 6.3**), and the predictions of the improved numerical groundwater model (including potential impacts of groundwater drawdown) described and presented in **Sections 8.0 and 9.0**. Uncertainty analysis has been undertaken in accordance with contemporary requirements (IESC Explanatory Note) and the groundwater model and groundwater assessment has been the subject of peer review by AGE Consultants (2020).
23	DES [1/32.1g]	*Significant detailed information is still required to assess the environmental risks associated with dewatering and impact to receptors that would likely result from the mining activity. Significant ongoing pre-disturbance monitoring and planning is required to manage the potential impacts to receptors in order to refine the proposed mitigation measure. Many of the mitigations appear to be dependent on impacts as they arise either from the actual activity, or are to be derived from the additional monitoring data (i.e. information is inconclusive).*	Significant detailed information has been provided to assess the environmental risks and is supported by Uncertainty Analysis undertaken in accordance with contemporary requirements (IESC Explanatory Note). As described in **Section 7.9**, the improved numerical groundwater flow model confidence is considered fit for purpose in accordance with the Australian Groundwater Modelling Guidelines (Barnett *et al*., 2012). The overall confidence level classification is considered to be Class 2, and capable of a number of specific uses, and most relevantly is capable of providing estimates of dewatering requirements for mines and excavations and the associated impacts; and is capable of providing impact predictions of proposed developments in medium value aquifers. Uncertainty analysis has been undertaken in accordance with contemporary requirements (IESC Explanatory Note) and the groundwater model and groundwater assessment has been the subject of peer review by AGE Consultants (2020). **Section 10.0** outlines the proposed groundwater monitoring program, which not unlike other developments similar in nature, would continue to collect baseline datasets in advance of and during the commencement of mining activities, in support of ongoing validation and monitoring, including review (and reporting) of the numerical groundwater model on a periodic basis. Such monitoring programs and triggers (i.e. TARPs) allow for early detection / trends to enable precautionary and adaptive management to be implemented as and if required, including contingency planning. Nevertheless, refined impact predictions have been made at receptors identified (including private landholders based on the result of past landholder bore survey) and other features in **Section 8.7**. As described in **Section 7.4.3 (Table 7-4)**, it is noted the improved model mesh design allowed for cells to be centred at receptors for specific analysis. Using the refined groundwater drawdown impact predictions at the receptors, specific mitigation / make good measures have been proposed and are presented in **Section 10.8**. Cognisant of Qld Baseline Assessment guideline, where specific mitigation / make good measures are proposed, targeted bore surveys and information collection would be undertaken as described in **Section 10.8**.

Table A1-2 (Continued)
Summary of Department of Environment and Science (DES) Submission Comments – Updated August 2019 [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
24	DES [1/32.1h]	*Based on the information provided, for the project to proceed, robust conditioning would be required to ensure that all potential impacts are adequately monitored and the receiving environment protected. Based on the length of time (as modelled) for the groundwater to recover, and the likely impacts to the receiving environment in the event that pools dry up, any approval should consider applying financial assurance for the entirety of the groundwater recovery timeframe.* *Note: The department notes a responsible entity would need to manage the supplementary supply of water into the creek system for many years to come after mine closure.*	**Section 10.0** outlines the proposed groundwater monitoring program, which not unlike other developments similar in nature, would continue to collect baseline datasets to augment the existing datasets, in advance of and during the commencement of mining activities, in support of ongoing validation and monitoring, including review (and reporting) of the numerical groundwater model on a periodic basis. Such monitoring programs and triggers (i.e. TARPs) allow for early detection / trends to enable precautionary and adaptive management to be implemented as and if required, including contingency planning. As described in **Section 10.6**, a Receiving Environment Monitoring Program (REMP) would be developed to ensure groundwater and surface water is adequately monitored. As demonstrated by the baseline data collection program (**Sections 3.0 and 5.0**), in-stream pools in drainage lines and watercourses have naturally dried up (and/or levels receded substantially) during the extended below average rainfall period in the vicinity of CQC Project area. Predicted changes in baseflow (i.e. reduced contributions / enhanced leakage) in Tooloombah Creek and Deep Creek have been modelled and are presented in **Section 8.6**. The Model Predicted Flux – Indirect Baseflow Changes / Enhanced Leakage During and Post-Mining are shown on **Graph 8-3**, and comparison of specific reaches on Tooloombah Creek provided on **Graph 8-4**. The quantitative Uncertainty Analysis is presented in **Section 8.11.2** and key aggregate metrics are presented in **Table 8-8** to provide an indication of the magnitude of differences for the changes in baseflow / enhanced leakage estimates, and corresponding probabilities. Also refer to Response to **DAFF [1.1a]**. The predicted changes in groundwater baseflow contributions and/or enhanced leakage in Tooloombah Creek and Deep Creek have been determined based on the improved numerical groundwater model. The corresponding volumetric changes in stream flow (and interflow) frequency and pool persistence, and consequential impacts on riparian vegetation and aquatic ecosystems is assessed separately by WRM Water & Environment (2020) and Eco Logical Australia (2020), respectively. No supplementary water inputs are proposed by CQCPL for the CQC Project, therefore do not require consideration for future groundwater model validation (i.e. as a potential future input to streamflow). However, it is noted that controlled water releases may occur as outlined in WRM Water & Environment Pty Ltd (2020). Record-keeping of such additional water volumes/inputs would be important to inform future groundwater model validation and is relevantly noted as a component of the REMP. The extent of predicted drawdown, and corresponding model estimated (quantified) changes in volume of base flows (including leakage) in areas adjacent to and downstream of the CQC Project demonstrates that the reductions would be negligible and indiscernible including the connected (downstream) estuarine areas. For example, the model predicted peak difference in the annualised flows from the Broad Sound Fish Habitat Area as a result of the CQC Project is <0.002 ML/year. As shown on **Graphs 8-3 and 8-4**, the residual differences for Broad Sound Declared Fish Habitat Area, Styx River and downstream Tooloombah Creek reach (below the Deep Creek confluence) asymptote to zero post closure of the mine. Therefore, based on the above, application of a financial assurance mechanism for supplementary water supply would not be warranted.

Table A1-2 (Continued)
Summary of Department of Environment and Science (DES) Submission Comments – Updated August 2019 [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
25	DES [2/32.35]	*Include detailed information on the concentration of contaminants expected in the mine affected water.* *Relevant information in Chapter 8 (Section 8.9 and Table 8-12) should be updated and referenced in the surface water Chapter 9, Section 9.9.*	**Groundwater is one input to mine affected water**. Surface water and groundwater quality datasets are presented in **Sections 3.2.7 and 5.5**. Based on the available datasets, the groundwater quality for the hydrogeological units, relevant WQOs and conceptualisation is discussed in **Sections 6.1, 6.2 and 6.3**. Importantly, specific consideration for water quality analytes is made based on the geochemical abundance and geochemistry of the waste rock and coal reject materials (**Section 4.5**) and discussed in **Sections 5.5 and 6.2**. Refer to separate assessment by WRM Water & Environment (2020), which describes the range of water quality concentrations in mine affected water (and their sources, including groundwater inflows, rainfall runoff from disturbed and undisturbed catchments, and recycling), and demonstrates that controlled releases (if required) could comply for key WQ parameter(s). Orange Environmental is updating the SEIS Chapters separately.
26	DES [3/32.39]	*The EIS should adequately assess the potential increased risk of stream bed and bank erosion and the potential impacts to aquatic fauna as a consequence of bed mobilisation.* *The sediment loads exported to the Great Barrier Reef World Heritage Area (GBRWHA) should be assessed and effectively managed and suitable monitoring proposed …* *Provide load estimation analysis, particularly as it relates to potential downstream impacts.* *Provide a comprehensive Draft Receiving Environmental Monitoring Program (REMP) in the amended EIS. The REMP must include a monitoring program for sediment load and particle size distribution to assess the potential impacts from stream bed/bank erosion and sediment mobilisation. Findings from sediment monitoring must be considered in the Water Management Plan and Erosion and Sediment Control Plan annual revision.* *The REMP must be consistent with the department's Receiving environment monitoring program guideline (ESR/2016/2399).*	**Not specifically a Groundwater-Related Matter.** However, **Section 4.6** presents an overview of the bed and bank stability of watercourses based on the fluvial geomorphology assessment (**Attachment 6**), which complements the findings of the TEM survey report by Groundwater Imaging (2019) (**Attachment 5**). Importantly, it is worth noting that **Section 4.0** relevantly describes the Early Cretaceous and Permian sedimentary sequences which have been deposited in the Styx Basin and Bowen Basin, as well as soils and Cenozoic sediment mapping. Reference to the Water Management Plan, Erosion and Sediment Control Plan(s) and Receiving Environment Monitoring Program is presented in **Sections 10.2, 10.2.1 and 10.6** respectively. Importantly, each of these plans/programs include elements which form part of the Groundwater Dependent Ecosystem Management and Monitoring Plan (GDEMMP) (**Section 10.5**). Refer to separate assessments by WRM Water & Environment (2020) and Fluvial Systems (2020). A draft *Conceptual Erosion and Sediment Control Plan* has been prepared by Engeny Water Management (2020). Controlled water releases, structures and up-catchment diversions are considered separately in WRM Water & Environment (2020). Orange Environmental is coordinating the preparation of the draft Receiving Environment Monitoring Program by Eco Logical Australia Pty Ltd (2020c).

Table A1-2 (Continued)
Summary of Department of Environment and Science (DES) Submission Comments – Updated August 2019 [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
26	*[As Above, Cont.]*	*Provide a detailed Draft Erosion and Sediment Control Plan (ESCP) developed by an appropriately qualified person (Certified Professional in Erosion and Sediment Control and Registered Professional Engineer of Queensland) in the amended EIS. The ESCP must:* *1. Demonstrate how ESC control measures adequately minimise the release of sediment to receiving waters and must include at least the following:* *a. Assessment of all catchment areas* *b. Assessment of soil types, including sodic dispersive soils* *c. Specify design criteria for ESC structures* *2. Detail the locations and descriptions of all ESC measures* *3. Provide an audit schedule to ensure ESC controls are maintained.*	*[As Above, Cont.]*
27	DES [4/32.54]	*The EIS provides some additional information in Table 10-80 describing effects, exposure and threat assessment. Update the revised EIS to ensure this information clearly describes all potential contaminants of concern, potential sources of contaminants and linkages to proposed monitoring and licencing approaches.* *The department notes a recent information guideline explanatory note – "Deriving site-specific guideline values for physico-chemical parameters and toxicants" available from the IESC website at:* ***http://www.iesc.environment.gov.au/publications/information-guidelines-explanatory-note-deriving-site-specific-guidelines-values***	Specific consideration for water quality analytes is made based on the geochemical abundance and geochemistry of the waste rock and coal reject materials (**Section 4.5**) and discussed in **Sections 5.5 and 6.2**. The proposed groundwater and surface water quality triggers are described in **Sections 10.1.10 and 10.1.11** and the draft EA conditions including draft groundwater quality investigation trigger levels reflecting relevant EVs / WQOs and metals/metalloids. It is noted that groundwater and groundwater dependent ecosystems are not covered in the IESC Explanatory Note, and whilst the concepts presented may be relevant to groundwater, it is explicitly recommended in the explanatory note that specific advice be sought regarding deriving suitable groundwater guideline values. Refer to separate assessment by WRM Water & Environment (2020).

Table A1-2 (Continued)
Summary of Department of Environment and Science (DES) Submission Comments – Updated August 2019 [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
28	DES [5/32.55]	*Amend the EIS to assess whether expected changes in topography would influence aquifer recharge.*	As described in **Section 8.3.6**, final landform designs were provided by CQCPL and updates presented in the designs by Alpha-Mine Planning 4U (2020). With the exception of the two out-of-pit waste rock emplacement areas, the final landform (after backfilling) generally reflects the pre-mining ground surface levels across the mined area. The final landform design surface is shown on **Figure 8-3**. As described in **Section 8.3.3**, the backfilling process was simulated in the numerical groundwater model with changes to hydraulic properties applied to the in-pit backfill spoil emplacement areas with elevations reflecting the backfilled final landform design surface. The elevated final rehabilitated landforms beyond the in-pit backfill spoil emplacement areas have been simulated in Layer 1 of the numerical groundwater model with elevations of up to 75 m above the pre-mining ground surface levels. The following characteristics have been applied to such areas: higher permeability of the spoil (broken, less unconsolidated rock); higher infiltration rate (enhanced rainfall recharge in spoil); and higher evapotranspiration surface (absolute), however the evapotranspiration rates and depths from the surface remain unchanged. Orange Environmental is updating the SEIS Chapters separately.
29	DES [5/32.56a]	*Demonstrate that the long-term modelling of the impacts and mitigation measures for GDEs will be undertaken during all stages of the mining operations and for a minimum of 100 years post mining.*	As described in **Section 7.6** (**Table 7-9**), the improved numerical groundwater model simulation periods for the prediction and recovery scenarios include all stages of the mining operations and long-term post-mining period in excess of 100 years: • Transient Prediction – Prelude (Stress Periods 60-68 – Monthly Increments) [October 2019 to June 2020]; • Transient Prediction – Mining (Stress Periods 69-284 – Monthly Increments) [July 2020 – June 2038]; • Transient Recovery – Mine Closure [Backfill] (Stress Periods 285-296 – Monthly Increments) [July 2038-June 2039]; • Transient Recovery – Mine Closure (Stress Periods 297-300 – Annual Increments) [July 2039-December 2042]; • Transient Recovery – Post-Mining (Stress Periods 301-319 – 5 Year Increments) [January 2043-December 2138]; and • Transient Recovery – Long-term (Stress Period 320 – 400 Year Increment) [January 2139-December 2538]. The predicted impacts and mitigation measures for GDEs are discussed in **Sections 8.7, 9.0 and 10.0**. As shown on **Graph 8-3 and 8-4**, the residual differences asymptote to zero or are balanced (asymptote) post closure of the mine as a new steady state is achieved.
30	DES [5/32.56b]	*GDEs must be protected from environmental harm caused directly and indirectly from mining activities. The department considers that the monitoring and mitigation measures proposed for GDEs should not be incorporated within a REMP as proposed. The department recommends that a specific management plan to manage impacts to GDEs is drafted to an advanced level, commensurate with the identified environmental risks, for assessment.*	Assessment of potential impacts on GDEs is described in **Sections 8.7 and 9.0**. Reference to the Groundwater Dependent Ecosystem Management and Monitoring Plan (GDEMMP) (**Section 10.5**), including a groundwater dependent ecosystem and wetland monitoring program is provided in **Section 10.5.1**. Orange Environmental is coordinating the preparation of the draft GDEMMP separately by Eco Logical Australia Pty Ltd (2020b).

Table A1-2 (Continued)
Summary of Department of Environment and Science (DES) Submission Comments – Updated August 2019 [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
31	DES [5/32.56c]	*A detailed draft Groundwater Dependent Ecosystem Management and Monitoring Plan (GDEMMP) must be developed and certified by an appropriately qualified person that addresses all phases of the mining operation. The GDEMMP must meet the following objectives:* *a) Validation of groundwater numerical model (including review of boundary and recharge conditions) to refine and confirm accuracy of groundwater impacts predicted* *b) Groundwater level monitoring in all identified geological units present across and adjacent to the mine site to confirm existing groundwater flow patterns and monitor drawdown impacts* *c) Identification of groundwater drawdown level thresholds for monitoring the impacts on GDEs* *d) Monitoring of aquifers identified as potentially being impacted from groundwater drawdown* *e) Identify and refine potential impacts of groundwater levels* *f) To ensure all potential groundwater impacts from mine dewatering and mine water and waste storage facilities are identified, mitigated and monitored* *A draft GDEMMP must be submitted for assessment by the department in the amended EIS.*	Reference to the Groundwater Dependent Ecosystem Management and Monitoring Plan (GDEMMP) (**Section 10.5**), including a groundwater dependent ecosystem and wetland monitoring program is provided in **Section 10.5.1**. Orange Environmental is coordinating the preparation of the draft GDEMMP separately by Eco Logical Australia Pty Ltd (2020b).
32	DES [7/32.57]	*The monitoring approach proposed in the amended EIS is not supported. Monitoring should be quarterly in the first instance and where it can be demonstrated that there is a need to reduce monitoring that a process of review be undertaken prior to reducing sampling frequency.*	As described in **Section 10.10**, quarterly groundwater monitoring is now proposed in the draft EA conditions, with an administrative mechanism to reduce the sampling frequency in the future. Nevertheless, sampling may be undertaken on a more frequent basis in advance of mining activities to augment baseline datasets if and as required.

Table A1-2 (Continued)
Summary of Department of Environment and Science (DES) Submission Comments – Updated August 2019 [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
33	DES [8/32.59]	*Describe post closure flooding impacts of diversions. Discuss how diversions would be constructed to be safe, stable and non-polluting during operation and closure. Assess the potential impacts of the diversion on the floodplain.*	**Not specifically a Groundwater-Related Matter.** However, **Section 4.6** presents an overview of the bed and bank stability of watercourses based on the fluvial geomorphology assessment (**Attachment 6**), which complements the findings of the TEM survey report by Groundwater Imaging (2019) (**Attachment 5**). Importantly, it is worth noting that **Section 4.0** relevantly describes the Early Cretaceous and Permian sedimentary sequences which have been deposited in the Styx Basin and Bowen Basin, as well as soils and Cenozoic sediment mapping. Annual mine progression plans (including in-pit backfill scheduling) were provided by CQCPL and updates presented in the designs by Alpha-Mine Planning 4U (2020). Notably the Project layout has been amended to reduce the post closure flooding impacts. Refer to separate assessments by WRM Water & Environment (2020) and Fluvial Systems (2020).
34	DES [9/32.59[2]]	*Clarify whether the diversions described in Table 11-15, under the Waste rock stockpile and Water infrastructure domains are the same drainage diversions which are described in Section 11.3.3.2.*	**Not specifically a Groundwater-Related Matter.** Annual mine progression plans (including in-pit backfill scheduling) were provided by CQCPL and updates presented in the designs by Alpha-Mine Planning 4U (2020). Notably the Project layout has been amended to reduce the post closure flooding impacts. Section 8.3 describes the application for key processes in the improved numerical groundwater model. Orange Environmental is updating the SEIS Chapters separately.
35	DES [10/32.60]	*In the event that dams associated with the waste rock stockpiles are retained – a clear statement is required to outline any residual risk or associated ongoing management.* *Completion criteria / indicators must clearly identify and measure that the final rehabilitated landform is not producing acid or saline drainage. Completion criteria are set to achieve a non-polluting objective, the following criteria should be added – 'runoff and seepage will be good quality water that is unlikely to adversely impact known environmental values'.*	**Not specifically a Groundwater-Related Matter.** However, **Section 10.3.1** provides an outline of the proposed groundwater (seepage) monitoring for rejects. **Section 8.3** describes the application for key processes in the improved numerical groundwater model, including water storage dams in **Section 8.3.5**. A summary of the geochemical abundance and geochemistry for waste rock and coal rejects (including solution extracts) is summarised in **Section 4.5**. Relevant Water Quality Objectives (WQOs) and corresponding groundwater quality triggers are provided in **Section 10.10**. Refer to separate assessment by RGS (2020) considering the geochemistry testwork results. Orange Environmental is updating the SEIS Chapters separately, including statement of residual risk or ongoing management.

Table A1-2 (Continued)
Summary of Department of Environment and Science (DES) Submission Comments – Updated August 2019 [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
36	DES [11/32.83]	*Provide a justification that the location and extent of the* [flora] *survey sites…*	**Not specifically a Groundwater-Related Matter.**
37	DES [11/32.85]	*Understanding the distribution and extent of fauna in the Deep Creek area is necessary as a haul road is proposed to cross Deep Creek. Provide a justification in section 14.5.2.3 for the lack of* [fauna] *survey sites along Deep Creek…*	**Not specifically a Groundwater-Related Matter.**
38	DES [13/32.90a]	*.. explain the steps taken to avoid, minimise, or mitigate impacts to regulated vegetation (i.e. could the water infrastructure be located elsewhere; if not, why not?). This could include an options analysis, and clearly outline how and why the proposed locations are the most suitable.*	**Not specifically a Groundwater-Related Matter.**
39	DES [13/32.90b]	*A portion of the regulated vegetation (wetland) is proposed to be cleared. A 1 hectare (ha) offset has been proposed for the loss. …* *The amended EIS should assess whether the proposed partial clearing of the wetland would alter the hydrology of the remaining extent of the wetland.*	**Not specifically a Groundwater-Related Matter.** Refer to separate response by Eco Logical Australia (2020a).
40	DES [14/32.97a]	*Baseline and GDE studies (including mitigation and management measures) will be a requirement in any approval. Provide an assessment on the risk of reduced baseflow to hydraulic heads, groundwater recharge and surface water flow. Should baseflow cease, the ecosystem is no longer groundwater dependent. Provide an assessment of the environmental water requirements of the ecosystem and the contribution of groundwater to inform potential impacts and environmental risks. Include a predicted effect on altered hydraulic gradients and the potential for increased duration of stream recharge.*	As shown on **Graph 8-3**, the model predicted changes to the Styx River reaches (2 and 3) downstream of the CQC Project, and upstream of the Broad Sound Declared Fish Habitat Area (FHA-047), including the section traversing the historic mine workings at Styx No.3 State Coal Mine are less than 0.0003 m^3/s for the combined 6.1 km length. When considering the downstream Styx River reaches are subject to tidal influences as well as rainfall runoff from downstream contributing catchments, including Granite Creek and Montrose Creek, such model predicted volumetric differentials are considered negligible and would be indiscernible. As shown on **Graph 8-4**, the model predicted changes to the Tooloombah Creek reach (1) downstream of Deep Creek confluence including the section downstream of the historic mine workings at Bowman are less than 0.0002 m^3/s for the 1.7 km length. When considering the downstream Tooloombah Creek reach is subject to tidal influences (i.e. within the identified tidal transition zone) as well as rainfall runoff from contributing catchments, including Tooloombah Creek and Deep Creek, such model predicted volumetric differentials would be indiscernible. Refer to separate assessments by Eco Logical Australia (2020a; 2020d).

Table A1-2 (Continued)

Summary of Department of Environment and Science (DES) Submission Comments – Updated August 2019 [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
41	DES [14/32.97b]	*It is recommended that the assessment develops baseline and developed scenario conceptualisations for groups of GDEs identified that explicitly identify critical hydrogeological and ecological factors. This conceptualisation informs numerical modelling including, for example, streambed conductivity and aquifer parameters.* *Provide reference to the 'EIS information guideline – Groundwater dependent ecosystems' around the development of conceptualisations, consideration of potential impacts, and avoidance and mitigation measures in the proposed monitoring plan. This information should be included in a draft GDEMMP.*	A draft Groundwater Dependent Ecosystem Management and Monitoring Plan (GDEMMP), including a GDE and wetland monitoring program is being developed by Eco Logical Australia (2020b), cognisant of the *EIS Information Guideline – Groundwater Dependent Ecosystems* (DEHP, 2016) and IESC *Information Guidelines Explanatory Note: Assessing Groundwater-Dependent Ecosystems* (dated 8 March 2019). The GDEMMP is prepared to identify (based on the conceptualisation [**Section 6.3**] and numerical model predictions [**Section 8.0**]) and refine the potential impacts described in **Section 9.0** to ensure all potential consequential effects from mine dewatering (**Sections 8.3 and 8.4**), mine water storage/management (WRM Water & Environment, 2020) and mineral waste management (**Section 10.3**) are identified, mitigated and monitored. As described in **Section 10.5**, the GDEMMP would include processes for numerical groundwater model review and validation, and more specifically review of applied boundary and recharge conditions (as outlined in **Section 7.5**). Applied streambed conductivity (i.e. 0.01 m/day) and spatially variable aquifer parameters (**Attachment 11**) for the groundwater model layers could also be considered during future model validation processes. During the penultimate stage of the peer review, it was recommended that river bed conductance also be investigated and has been considered separately in **Section 8.11.6**. Required offsets for GDEs and species considering any significant residual impacts (**Section 11.1**) would also be identified in the GDEMMP.
42	DES [15/32.97a]	*The potential impact of saltwater ingress on freshwater aquatic or terrestrial groundwater dependent species should be addressed in the revised SEIS.*	**Refer to Response to DAFF [1.6].** Despite the above conclusions based on the broad conceptualisation (**Section 6.3.2**), scenario based sensitivity analysis has been undertaken as part of the uncertainty analysis (**Section 8.11.3**) to investigate low (2 mAHD) and high (4.5 mAHD) constant head (seawater) boundary conditions and, complemented with use of USG-Transport software, modelled the differences. As shown on **Figures 8-7[a] and 8-7[b]**, the differences in maximum predicted groundwater drawdown in Layers 2 and 8 are negligible despite there being a 2.5 m differential in the fixed head boundary condition. Thus, changes to the inferred freshwater-seawater interface based on the broad conceptualisation would be indiscernible.
43	DES [15/32.97b]	*Provide detailed information that shows the modelling of the tidal/estuarine zone during and post mining.*	**Refer to Response to DES [15/32.97a].** As stated in the AGE Consultants peer review (2019): *The surface processes in the tidal zone of Styx River are dynamic, however on the timeframes that the groundwater model operates it is entirely appropriate to represent this as a constant head.*
44	DES [16/32.99]	*Provide evidence that the proposed supplementary water mitigation measure would be effective in mitigating the loss of stygofauna specific and habitat. Include evidence to support expected stygofauna mobility within the water column at proposed drawdown rates.*	Assessment of predicted impacts on stygofauna habitat is described in **Section 8.7.4**. Notably, **Section 5.3.4** explains that of the sampling sites which recorded the presence of subterranean fauna classed as stygofauna (i.e. Habitus = Phreatobite or Stygobite), only Exploration Hole STX093 (near Deep Creek) was in the vicinity of the CQC Project, and reported the presence of water mites, but the Order (Astigmata) remained in question (Yeats Consulting, 2012). One of the groundwater fauna recorded at STX093 was also not a stygofauna animal (i.e. edaphobite).

Table A1-2 (Continued)
Summary of Department of Environment and Science (DES) Submission Comments – Updated August 2019 [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
44	*[As Above, Cont.]*	*[As Above, Cont.]*	Notably all the 'Riverside' sampling locations which recorded stygofauna were located toward the Styx River mouth, downstream of the CQC Project. Refer to separate assessment by Eco Logical Australia (2020a). The extent of predicted drawdown, and corresponding model estimated (quantified) changes in volume of base flows (including leakage) in areas adjacent to and downstream of the CQC Project demonstrates that the reductions would be negligible and indiscernible including the connected (downstream) estuarine areas. For example, the model predicted peak difference in the annualised flows from the Broad Sound Fish Habitat Area as a result of the CQC Project is <0.002 ML/year. As shown on **Graphs 8-3 and 8-4**, the residual differences for Broad Sound Declared Fish Habitat Area, Styx River and downstream Tooloombah Creek reach (below the Deep Creek confluence) asymptote to zero post closure of the mine. No supplementary water inputs are proposed by CQCPL for the CQC Project, therefore do not require consideration for future groundwater model validation (i.e. as a potential future input to streamflow). However, it is noted that controlled water releases may occur as outlined in WRM Water & Environment Pty Ltd (2020). Record-keeping of such additional water volumes/inputs would be important to inform future groundwater model validation and is relevantly noted as a component of the REMP.
45	DES [17/32.100]	*Clearly describe how impacts would be defined should mitigation measures be unsuccessful. How would offsets then be applied?* *All required offsets for GDEs and species must be identified within the GDEMMP.*	**Refer to Response to DAFF [1.2].** The potential impacts on listed threatened species and communities and migratory species are assessed separately by Eco Logical Australia Pty Ltd (2020a) and proposed offsets considered separately by others. Required offsets for GDEs and species considering any significant residual impacts (**Section 11.1**) would also be identified in the GDEMMP, a draft of which has been prepared by Eco Logical Australia Pty Ltd (2020b).
46	DES [1/32.1]	*Amend the revised EIS to ensure mine affected water is not treated via environmental dams.*	**Not specifically a Groundwater-Related Matter.** **Refer to Response to DES [2/32.35].** The site water management practices are described in WRM Water & Environment (2020).
47	DES [2/32.7]	*Provide analysis of the potential for the worst-case scenario of riparian and terrestrial ecosystem collapse from groundwater drawdown impacts. This would require an assessment of potential sediment loads to the GBR in order to fully consider the risk of the supplementary water mitigation measure not being successful.* *The amended EIS should assess the potential consequential impacts from bank slumping and sediment export mobilised by potential flood events to downstream sensitive ecosystems.*	Assessment of predicted impacts on GDEs is described in **Section 8.7.2**. **Section 4.6** presents an overview of the bed and bank stability of watercourses based on the fluvial geomorphology assessment (**Attachment 6**), which complements the findings of the TEM survey report by Groundwater Imaging (2019) (**Attachment 5**). Importantly, it is worth noting that **Section 4.0** relevantly describes the Early Cretaceous and Permian sedimentary sequences which have been deposited in the Styx Basin and Bowen Basin, as well as soils and Cenozoic sediment mapping. Refer to separate assessments by WRM Water & Environment (2020) and Fluvial Systems (2020).

Table A1-2 (Continued)
Summary of Department of Environment and Science (DES) Submission Comments – Updated August 2019 [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
47	*[As Above, Cont.]*	*A sediment load monitoring program must be undertaken upstream and downstream of the proposed mine area. The program should assess the potential impacts of mining operations, including mine affected water releases, stormwater releases through Erosion and Sediment Control structures and watercourse diversions, on the watercourse channel bed load, including the contribution of sediment from the mine to the Styx catchment.* *Provide a detailed assessment on whether significant mobilised sediment loads entering the Styx River system and Broad Sound would potentially cause adverse impacts on habitat for listed migratory species, fish habitat values of the Broad Sound Fish Habitat Area and on the values of the GBRWHA.*	**Not specifically a Groundwater-Related Matter.** A draft *Conceptual Erosion and Sediment Control Plan* has been prepared by Engeny Water Management (2020). Controlled water releases, structures and up-catchment diversions are considered separately in WRM Water & Environment (2020). **Refer to Response to DAFF [1.2 and 1.9]** and separate assessment by Fluvial Systems (2020).
48	DES [3/32.8a]	*Provide a detailed analysis of the examples of supplementary water. This information should address the relevance of these examples to the proposed project; and the overall effectiveness of these examples in achieving the objective of reducing and/or eliminating potential environmental impacts. Describe how the supplementary water mitigation measure would be undertaken to demonstrate it would achieve its intended purpose. Provide further information and a detailed assessment of the suitability of using mine produced water. Provide details on the timing volumes and relationship to watering requirements for key species and ecosystem functions. This should include, but not be limited to, an aquatic food web analysis to show the potential impacts on the hyporheic zone; consumer's energy requirements and whether they obtain resources from autotrophic and/or detrital pathways (that may be limited by the impact); the relative importance of inorganic Carbon-rich groundwater; and how biota inhabiting pools will adapt to the loss of connectivity and changes in water quality.*	The extent of predicted drawdown, and corresponding model estimated (quantified) changes in base flows (including leakage) in areas adjacent to and downstream of the CQC Project demonstrates that the reductions would be negligible and indiscernible including the connected (downstream) estuarine areas. For example, the model predicted peak difference in the annualised flows from the Broad Sound Fish Habitat Area as a result of the CQC Project is <0.002 ML/year. As shown on **Graphs 8-3 and 8-4**, the residual differences for Broad Sound Declared Fish Habitat Area, Styx River and downstream Tooloombah Creek reach (below the Deep Creek confluence) asymptote to zero post closure of the mine. No supplementary water inputs are proposed by CQCPL for the CQC Project, therefore do not require consideration for future groundwater model validation (i.e. as a potential future input to streamflow). However, it is noted that controlled water releases may occur as outlined in WRM Water & Environment Pty Ltd (2020). Record-keeping of such additional water volumes/inputs would be important to inform future groundwater model validation and is relevantly noted as a component of the REMP.

Table A1-2 (Continued)
Summary of Department of Environment and Science (DES) Submission Comments – Updated August 2019 [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
49	DES [3/32.8b]	*The amended EIS should include a more robust pools water balance model that includes multiple sampling over different seasons for all identified pools.* *The baseline pools assessment should identify the number of pools that may be subject to drawdown, including, but not limited to: their dimensions; their location; their in-stream aquatic habitat features; their longevity in the dry season; their likely surface water and groundwater connectivity and threshold dependency on groundwater in the dry season/drought cycle.* *Specific analysis is required to account for operational phase impacts. The assessment must be undertaken by a suitably qualified person with hydrology / GDE ecology expertise.*	As shown in **Graph 7-3**, calibration datasets were extended and the long term historical below average rainfall trends can be observed in the model outputs as well as more recently (2018-2019) (**Attachment 8**) with changes in groundwater levels corresponding with below average rainfall periods around the 1960s, 2000s and approaching 2020. Additional stream flow gauging and corresponding datalogging in nearby alluvium bores (WMP04, WMP05 and WMP29A) is also presented in **Section 3.3**. Relevantly, given the recent extended period of dry (and no flow) conditions recorded in many of the local drainages as well as pools which had since dried from mid-2019 in Deep Creek and pool levels receding in Tooloombah Creek (with increasing salinity reflecting potentially evapo-concentration effects and/or groundwater inputs), rainfall runoff is demonstrably likely to be the primary source of stream flow across the CQC Project area. Photographic plates in **Section 3.0** demonstrate the ephemeral nature (or otherwise) of pools along Tooloombah Creek and Deep Creek, subject to potential/predicted effects of groundwater drawdown, considering groundwater connectivity (**Section 7.7.6**). A separate groundwater model validation exercise has been completed utilising pool survey elevations along the reaches of Tooloombah Creek and Deep Creek and is presented in **Section 7.8**. Refer also to separate assessments by Eco Logical Australia (2020d), developed with input from WRM Water & Environment (2020).
50-66	DES [1-19]	*Varies.*	**Not specifically Groundwater-Related Matters.**
67	DES [20]	*Ensure all conditions requiring water monitoring related data and reports include the requirement to submit to the department's WaTERS database.*	Addressed in **Section 10.10** (draft EA Condition) and is referred to in **Section 10.7**.
68-75	DES [21-28]	*Varies.*	**Not specifically Groundwater-Related Matters.**

Table A1-3
Summary of Department of the Environment and Energy (DEE) Submission Comments [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
76	DEE [21]	*The limited time series data informing the model is not adequate to characterise the likely seasonal variations in groundwater levels and the model's ability to predict future variability. …*	**Refer to Section 5.0 which presents the groundwater datasets and describes the dependent assets (including groundwater connectivity and dependency).** The groundwater monitoring network installed within ML 80187, ML 700022 and surrounds is extensive and has been progressively developed as part of initial exploration and groundwater investigation programs (i.e. 2010-11, 2011-12 and 2014), through to targeted and detailed groundwater investigations, bore census and baseline monitoring network installations (and extensions) in 2017 and 2018, and supplementary groundwater investigations and continued baseline groundwater monitoring in 2019 to support improvements to the groundwater modelling and assessments and future validation, including more recently: • continued monthly baseline groundwater level monitoring (and groundwater sampling for quality analysis) at the 2017 WMP Series (WMP02, WMP04, WMP04D, WMP05, WMP06, WMP07, WMP08, WMP08D, WMP09, WMP10, WMP11, WMP11D, WMP12, WMP13, WMP14, WMP15); • establishment of ongoing periodic (e.g. monthly) baseline groundwater level monitoring (and groundwater sampling for analysis) at the 2018 WMP Series (WMP15, WMP16D, WMP17, WMP17D, WMP18, WMP18D, WMP19, WMP19D, WMP20, WMP20D, WMP21, WMP22A, WMP22B, WMP22C, WMP23A, WMP24, WMP25, WMP26, WMP27, WMP28, WMP29A, WMP29B, WMP29C, WMP29D, WMP29E, WMP30A, WMP30B, WMP30C); • continued monthly baseline groundwater level monitoring (and groundwater sampling for quality analysis) at select landholder bores (BH01X and BH16); • regular (generally every 2nd day) on-site groundwater level recordings (and field groundwater quality testing) in select WMP Series (WMP04, WMP10, WMP22A, WMP24), exploration drill hole (STX1205L) and select waterholes / pools on Tooloombah Creek (Easting 772174; Northing 7489156) and Deep Creek 1 (Easting 774721; Northing 7485632) and Deep Creek 2 (Easting 775987; Northing 7485672) undertaken as part of the AMEC (2019) groundwater investigation; • continuous datalogging of alluvial groundwater levels in groundwater bores responsive to stream or flood recharge in Deep Creek (WMP05) [paired with new Gauging Station No. 330452], Tooloombah Creek (WMP04) [paired with new Gauging Station No. 330451] and the Styx River (WMP29A) [for comparison with Broad Sound tides and local observations at Ogmore Road Bridge crossing]; and • installation of a new VWP (WMP31) targeting the basement aquifers to the north-east (and east of the regional fault) targeting the Styx Coal Measures basement (i.e. Permian Measures – Back Creek Group). In addition to the above, several additional site-specific groundwater investigations have been undertaken in 2019 to support the groundwater monitoring datasets including: • transient electromagnetic (TEM) survey of groundwater associated with surficial geology (Groundwater Imaging, 2019) (**Attachment 5**); • open end permeability and packer testing at two exploration drill holes STX1901 and STX1902 (AMEC, 2019) (**Attachment 7**); and • core sampling from two exploration drill holes STX1812 and STX1903 and laboratory permeability testing (GES, 2020) (**Attachment 9**).

Table A1-3 (Continued)
Summary of Department of the Environment and Energy (DEE) Submission Comments [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
76	*[As Above, Cont.]*	*[As Above, Cont.]*	**Section 3.1.1 describes the historical rainfall trends (including cumulative deviation from the mean), which is presented on the calibration hydrographs (Attachment 8) along with the history-matching of the improved numerical groundwater model results based on historic mining and investigations presented in Section 7.5.6. Modelled groundwater connectivity with watercourses are also discussed in Sections 7.5.3 and 7.7.6, considering the available hydrological datasets presented in Section 3.3.** As shown in **Graph 7-3**, calibration datasets were extended and the long term historical below average rainfall trends can be observed in the model outputs as well as more recently (2018-2019) (**Attachment 8**) with changes in groundwater levels corresponding with below average rainfall periods around the 1960s, 2000s and approaching 2020.
77	DEE [21a]	• *the current bore network is not spatially appropriate to understand the nature of the groundwater system;*	**As demonstrated by the datasets available in Section 5.1, the extensive groundwater monitoring network has a reasonable spatial distribution in the vicinity of the CQC Project, and is made more robust through the installation of the eastern/north-east drill hole(s) targeting the Styx Coal Measures basement (i.e. Permian Measures).** The spatial groundwater levels are described in **Section 5.4.1** based extended datasets from the existing groundwater monitoring network. Model layer head plots are presented in **Attachment 13**. Initial groundwater level/pressure measurements at WMP31 are presented in **Attachment 8** (**Graph A8-54**). As discussed in **Section 10.1.7**, consideration should be given to installing an additional groundwater monitoring bore (deep standpipe) to the north / north-east of Open Cut 2, but to the west of the mapped fault (e.g. between WMP05 and WMP10) within the first three (3) years of the operation (NB: WMP21B was subsequently installed by CQCPL in April 2020). Whilst the new WMP31 VWP would provide validation of the expected presence of the fault (and potential barrier to flow) to the north-east/east, a location in the north would allow for early detection of the propagation of depressurisation effects in the deeper coal seams toward the north (and south of the historic mine workings) to compare with responses (if any) at WMP31 or trigger an adaptive management approach if required.
78	DEE [21b]	• *the location of the seawater-freshwater interface has not been determined and is not considered by the model;*	The location of the freshwater / saline interface, utilising the Ghyben-Herzberg relationship, is discussed in **Section 6.3.2**. As discussed in **Section 6.3.2**, WMP13 located several kilometres downstream of the CQC Project has recorded salinities indicative of seawater. As described in **Section 7.5.1**, based on a review of tidal influence and long-term sea level records (**Section 3.3**) the chosen elevation of the fixed head boundary applied was 3.5 mAHD. A sensitivity range of 2 mAHD (as previously modelled) to 4.5 mAHD has been considered in the uncertainty (sensitivity) analysis (**Section 8.11.3**). It is noted that the recorded long term mean sea levels are 3.42 mAHD and 2.47 mAHD at Hay Point and Rosslyn Bay respectively. Tide monitoring (at Ogmore Road Bridge) would continue to be recorded periodically to allow the range of predicted stage water levels in the Styx River to be validated and constant head boundary conditions (**Section 10.1.3**). Similarly, groundwater quality monitoring would continue to be undertaken at the WMP29 Series (A-E) Bores to inform any further freshwater / saline interface investigations, as and if required. Monitoring of elevated salinity at WMP26 (albeit above 7 mAHD) would also continue.
79	DEE [21c]	• *the bore monitoring timeframes are not sufficient to calibrate the model to a high level of accuracy;*	**The calibration approach is described in detail in Section 7.7.1 and the calibration statistics meet AGWM Guideline (Attachment 10).**

Table A1-3 (Continued)
Summary of Department of the Environment and Energy (DEE) Submission Comments [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
80	DEE [21d]	- *long-term pump tests have not been undertaken to provide a high level of confidence in understanding the groundwater system in the wider area;*	Representative site-specific data for hydraulic properties has been collected (through aquifer testing [CDM Smith, 2018] and core permeability testwork [GES, 2020]) as described in **Section 5.6**, and combined available literature review and prior modelling provides a basis for numerical groundwater flow modelling which has been tested as part of the Uncertainty Analysis (**Section 8.11 and Attachment 11**). Additional site-specific datasets are presented in **Attachments 7 and 9**.
81	DEE [21e]	- *the model is constrained by data derived from only shallower aquifers and does not provide a full representation of the hydrogeology of the project site and surrounds;*	The groundwater datasets used for the model are outlined in **Section 5.0** and is representative of the hydrogeological units including shallow, deeper and basement aquifers.
82	DEE [21f]	- *the backfilled final voids have not been appropriately parameterised in regards to their hydraulic properties;*	As described in **Section 8.3.3**, the backfilling process is simulated by applying Time-varying Material (TVM) properties to reflect the changes in the host rock properties (pre-mining) to reflect the backfill spoil (broken, less consolidated rock), and was applied generally consistent with the backfill schedule provided.
83	DEE [21g]	- *flood heights are not adequately represented in the model as there is no site-specific data on flooding events and long-term trends;*	Continuous datalogging of groundwater levels in the nearby Quaternary Alluvium bore (WMP05) and comparisons to the pool/stage levels in Deep Creek are also provided in **Section 5.4.2**. Continuous datalogging of groundwater levels in the nearby Quaternary (Pleistocene) Alluvium bore (WMP04) and future comparisons to the pool/stage levels in Tooloombah Creek are discussed in **Section 5.4.2**. Relevantly, evidence of flooding following the 2010-2011 flood event was noted during the ALS Water Sciences Group (2011) Baseline Aquatic Survey in June 2011 with debris in trees found 7-8 m above the measured water level at that time (**Section 3.3.4**). Photographic plates and previous stream mapping information to demonstrate the nature of watercourses and drainage lines across the site are presented in **Section 3.3**, including Tooloombah Creek and Deep Creek subject to potential/predicted effects of groundwater drawdown. Other potential influences including tidal fluctuations, storm tides, flood extents and sea level rise have also been considered.
84	DEE [21h]	- *there is a high level of uncertainty on the nature and extent of surface water-groundwater connectivity within and downstream of the project site.*	**Refer DAF [1.1 & 1.2] in Table A1-1.** Uncertainty analysis has been undertaken in accordance with contemporary requirements (IESC Explanatory Note) and the groundwater model and groundwater assessment has been the subject of peer review by AGE Consultants (2020) (**Attachment 2**).
85	DEE [21i]	- *the sensitivity and uncertainty analysis is not adequate given the high risks with the proposed action and its potential impacts on MNES.*	A combination of parameter identifiability, sensitivity and qualitative analyses have been used in **Section 8.11** to identify bounds (or constraints) by available observations and then investigate if and/or how such parameters affect the model predictions. This recognises the challenge of non-uniqueness, and the possibility that multiple combinations of parameters may be equally good at fitting historical measurements, but at the same time has been used in support of the combination of parameters applied. Robust quantitative uncertainty analysis was undertaken as detailed in **Section 8.11.2** and is presented in **Attachment 11**. Each of the four sources of scientific uncertainty affecting groundwater model simulations has been considered during the development of the improved numerical groundwater model and the uncertainties are discussed in **Section 8.12**, with respect to overall objectives. Notably, and according to the Risk Management - Principles and Guidelines Standard (AS/NZS) ISO 31000:2009, risk is defined in terms of the effect of uncertainty on objectives.

Table A1-3 (Continued)
Summary of Department of the Environment and Energy (DEE) Submission Comments [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
86	DEE [21j]	*The Department notes the outcomes of the groundwater model peer review have not been incorporated into mine planning and management.*	**Refer to Tables A2-1 to A2-6 in Attachment 2.**
87	DEE [3, 11, 21a]	*Due to the Department's low confidence in the groundwater model predictions, the Department considers the AEIS does not provide an adequate assessment of potential groundwater drawdown impacts on riparian vegetation, surface water-groundwater connectivity, aquatic ecosystems (particularly waterholes), stygofauna, wetlands and surface water quality.*	As described in **Section 7.9**, the improved numerical groundwater flow model confidence is considered fit for purpose in accordance with the Australian Groundwater Modelling Guidelines (Barnett *et al*., 2012). The overall confidence level classification is considered to be Class 2, and capable of a number of specific uses, and most relevantly is capable of providing estimates of dewatering requirements for mines and excavations and the associated impacts; and is capable of providing impact predictions of proposed developments in medium value aquifers. Uncertainty analysis has been undertaken in accordance with contemporary requirements (IESC Explanatory Note) and the groundwater model and groundwater assessment has been the subject of staged peer review by AGE Consultants (**Tables A2-4 to A2-6**). Refer to separate assessments by Eco Logical Australia (2020) and WRM Water & Environment (2020).
88	DEE [3, 11, 21b]	*There is the potential that the magnitude and spatial extent of groundwater drawdown has been underestimated.*	Robust uncertainty analysis, including identifiability analysis has been undertaken and the resulted presented in **Section 8.11** and **Attachment 11**.
89	DEE [3, 11, 21c]	*The Department notes this reduces the Department's confidence in the accuracy of the proponent's assessment of the impacts of the proposed action on other MNES. For example, a loss of riparian vegetation, which also forms habitat for listed threatened species, may destabilise the already incised creek banks and promote erosion in an already highly erosive area. This may increase the amount of sediment entering the Styx River system and Broad Sound, and potentially cause adverse impacts on habitat for listed migratory species and on the values of the Great Barrier Reef World Heritage Area (GBRWHA).*	**Refer to Response to DEE [3, 11, 21a], DES [2/32.7] and DAFF [1.2 and 1.9].** Assessment of predicted impacts on GDEs is described in **Section 8.7.2**. Further assessment is presented in Eco Logical Australia (2020a). **Section 4.6** presents an overview of the surficial deposition processes and bed and bank stability of watercourses based on input from the fluvial geomorphology assessment (**Attachment 6**), which complements the findings of the TEM survey report by Groundwater Imaging (2019) (**Attachment 5**). Importantly, it is worth noting that **Section 4.0** relevantly describes the Early Cretaceous and Permian sedimentary sequences which have been deposited in the Styx Basin and Bowen Basin, as well as soils and Cenozoic sediment mapping. Refer to separate assessments by WRM Water & Environment (2020), Fluvial Systems (2020) and Orange Environmental (2020). A draft *Conceptual Erosion and Sediment Control Plan* has been prepared by Engeny Water Management (2020). Controlled water releases, structures and up-catchment diversions are considered separately in WRM Water & Environment (2020).

Table A1-3 (Continued)
Summary of Department of the Environment and Energy (DEE) Submission Comments [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
90	DEE [3, 11, 21d]	*The Department considers the proponent's assessment of the downstream impacts associated with the controlled and uncontrolled release of sediment-laden water into surface watercourses to be inadequate.* *…the proponent's current assessment of surface water releases does not adequately consider the following:*	**Not specifically a Groundwater-Related Matter.** Controlled water releases, structures and up-catchment diversions are considered separately in WRM Water & Environment (2020).
91	DEE [3, 11, 21e]	• *sodic and highly dispersive nature of the soils within the project site;*	**Soil types and sodicity of waste rock based on the geochemistry testwork results are discussed in Sections 4.4 and 4.5.** Sodicity levels (in the form of ESP) was very high (28.9% to 42.7%) (CDM Smith, 2018k) and appeared to be generally consistent with site observations of eroded areas (e.g. adjacent to Deep Creek) and of *in-situ* aquifer testing of low permeability sequences (**Section 5.6.2**). Erosion and sediment control measures for such sodic soil types would be described in the Erosion and Sediment Control Plan. Reference to the Water Management Plan, Erosion and Sediment Control Plan and Receiving Environment Monitoring Program is presented in **Sections 10.2, 10.2.1 and 10.6** respectively. Importantly, each of these plans/programs include elements which form part of the Groundwater Dependent Ecosystem Management and Monitoring Plan (GDEMMP) (**Section 10.5**). A draft *Conceptual Erosion and Sediment Control Plan* has been prepared by Engeny Water Management (2020). Controlled water releases, structures and up-catchment diversions are considered separately in WRM Water & Environment (2020).
92	DEE [3, 11, 21f]	• *nature of the existing surface hydrology and severity of flood events (i.e. flood levels and frequency);*	Refer to separate assessment by WRM Water & Environment (2020). **Section 3.1.1 (Graph 3-2)** includes an overview of the three (3) flood events during the groundwater model calibration period.
93	DEE [3, 11, 21g]	• *sediment dilution and metal accumulation in high ecological value watercourses;*	Controlled water releases, structures and up-catchment diversions are considered separately in WRM Water & Environment (2020). Refer also to separate assessment by Fluvial Systems (2020).
94	DEE [3, 11, 21h]	• *the risks associated with the proposed action's proximity to the GBRWHA, …*	The location of the GBRWHA is described in **Section 2.2.2**. The Marine National Park Zone MNP-21-1146 (Broad Sound area including the Bedwell Group, Wild Duck and Bamborough Island) is defined in Part 6 of the Great Barrier Reef Marine Park Zoning Plan 2003. The nearest point of the Marine National Park Zone MNP-21-1146 to the Qld coastline is north of Charon Point and Rosewood Island, beyond the north-eastern boundary of the groundwater model domain (**Section 7.4**).

Table A1-3 (Continued)
Summary of Department of the Environment and Energy (DEE) Submission Comments [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
95	DEE [3, 11, 21i]	*There is a lack of detail in the proposed water management system regarding treatment of sediment and contaminant-laden water, in particular the identification of:*	**Not specifically a Groundwater-Related Matter.** Refer to separate assessment by WRM Water & Environment (2020). A draft *Conceptual Erosion and Sediment Control Plan* has been prepared by Engeny Water Management (2020). Controlled water releases, structures and up-catchment diversions are considered separately in WRM Water & Environment (2020).
96	DEE [3, 11, 21j]	• *the water source for each water storage;* • *likely water quality of each water storage and the 'worst case scenario' water quality (i.e. from extreme weather events);*	**Not specifically a Groundwater-Related Matter. Refer to Response DES [4/32.54].** Refer to separate response by WRM Water & Environment (2020) which provides an indication of the range of water quality concentrations in mine affected water (and their sources, including groundwater inflows, rainfall runoff from disturbed and undisturbed catchments, and recycling), and if necessary, demonstrate that releases (if required) could comply for key WQ parameter(s).
97	DEE [3, 11, 21k]	• *all receiving environments for all water storages;*	**Not specifically a Groundwater-Related Matter. Refer to Response DES [4/32.54].** Refer to separate response by WRM Water & Environment (2020) which provides an indication of the range of water quality concentrations in mine affected water (and their sources, including groundwater inflows, rainfall runoff from disturbed and undisturbed catchments, and recycling), and if necessary, demonstrate that releases (if required) could comply for key WQ parameter(s). Orange Environmental is coordinating the preparation of the draft Receiving Environment Monitoring Program by Eco Logical Australia Pty Ltd (2020c).
98	DEE [3, 11, 21l]	• *flood and extreme rainfall events that each water storage is designed to contain before an uncontrolled release occurs; and* • *the amount of freeboard that will be maintained.*	**Not specifically a Groundwater-Related Matter. Refer to Response DEE [3, 11, 21f].** Refer to separate response by WRM Water & Environment (2020).

Table A1-3 (Continued)
Summary of Department of the Environment and Energy (DEE) Submission Comments [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
99	DEE [3, 11, 21m]	*The Department considers that the commitment to develop and implement an Erosion and Sediment Control Plan (ESCP), without providing specific detail to manage impacts, is not adequate …*	**Not specifically a Groundwater-Related Matter.** Refer to separate assessment by WRM Water & Environment (2020). A draft *Conceptual Erosion and Sediment Control Plan* has been prepared by Engeny Water Management (2020). Controlled water releases, structures and up-catchment diversions are considered separately in WRM Water & Environment (2020).
100	DEE [3, 11, 21n]	*The proponent has not provided adequate information on the following:* - *identification of the location of the saltwater intrusion interface;* - *the potential for changes in the location of the saltwater intrusion on MNES.* *The Department considers a thorough assessment of the potential mobilisation of the saltwater intrusion interface, as a result of groundwater drawdown, is critical due to the potential impacts on MNES. The Department considers the proponent has not adequately demonstrated that the saltwater intrusion interface is located outside of the zone of predicted drawdown…*	The location of the freshwater / saline interface, utilising the Ghyben-Herzberg relationship, is discussed in **Section 6.3.2**. As discussed in **Section 6.3.2**, WMP13 located several kilometres downstream of the CQC Project has recorded salinities indicative of seawater. As described in **Section 7.5.1**, based on a review of tidal influence and long-term sea level records (**Section 3.3**) the chosen elevation of the fixed head boundary applied was 3.5 mAHD. A sensitivity range of 2 mAHD (as previously modelled) to 4.5 mAHD has been considered in the scenario-based sensitivity analysis (**Section 8.11.3**). It is noted that the recorded long term mean sea levels are 3.42 mAHD and 2.47 mAHD at Hay Point and Rosslyn Bay respectively. Tide monitoring (at Ogmore Road Bridge) would continue to be recorded periodically to allow the range of predicted stage water levels in the Styx River to be validated and constant head boundary conditions (**Section 10.1.3**). Similarly, groundwater quality monitoring would continue to be undertaken at the WMP29 Series (A-E) Bores to inform any further freshwater / saline interface investigations, as and if required. Monitoring of elevated salinity at WMP26 (albeit above 7 mAHD) would also continue.
101	DEE [3, 11, 21o]	*The Department notes the proponent has not undertaken:* - *adequate field surveys to identify the location of the saltwater intrusion interface, including in all aquifers and aquifers near the coast;* - *modelling of potential seawater intrusion and inundation to support the groundwater model;* - *a 'worst case scenario' to determine the maximum possible inland extent of saltwater intrusion;* - *an assessment of the potential for the saltwater interface to interact with the material in the backfilled final voids;*	**Refer to Response Above.** The broad conceptualisation for freshwater-saline water interface (Ghyben-Herzberg relationship) is described in **Section 6.3.2**. As demonstrated by the results of the uncertainty (sensitivity) analysis with constant head values of 2 mAHD and higher 4.5 mAHD (i.e. negligible change in the predicted groundwater drawdown extent), the vectors (gradients) during and post-mining remain in the upper layers of the model toward the lower reaches of the Styx River and would therefore not be expected to result in any discernible change in the freshwater-saline water interface as described in **Section 6.3.2**. Based on the groundwater quality results available at the existing groundwater monitoring network between the CQC Project and the coast (discussed in **Section 6.3.2**) at various depths and intervals in the Cenozoic sediments, Styx Coal Measures and Permian Back Creek Group, additional field groundwater surveys toward the coast were therefore not considered necessary.

Table A1-3 (Continued)
Summary of Department of the Environment and Energy (DEE) Submission Comments [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
101	[As Above, Cont.]	• *an assessment of the potential impacts of the mobilisation of the saltwater interface on ecological values, including riparian habitat for listed threatened species and communities; and* • *an assessment of the potential impacts of the mobilisation of the saltwater interface on the estuarine and marine ecosystems associated with the GBRWHA.*	[As Above, Cont.]
102	DEE [3, 11, 21p]	*The lack of confidence in the surface water model predictions arises from:*	**Not specifically a Groundwater-Related Matter.**
103	DEE [3, 11, 21q]	• *a lack of local streamflow gauging data;*	As shown in **Graph 7-3**, calibration datasets were extended and the long term historical below average rainfall trends can be observed in the model outputs as well as more recently (2018-2019) (**Attachment 8**) with changes in groundwater levels corresponding with below average rainfall periods around the 1960s, 2000s and approaching 2020. Additional stream flow gauging and corresponding datalogging in nearby alluvium bores (WMP04, WMP05 and WMP29A) is also presented in **Section 3.3**. Alluvial dataloggers have been installed at WMP04 (Tooloombah Creek), WMP05 (Deep Creek) and WMP29A (Styx River) to complement the stream flow gauging stations installed on Tooloombah Creek, Deep Creek and the opportunistic tidal monitoring location at the Ogmore Road Bridge.
104	DEE [3, 11, 21r]	• *no site-specific information on the current state of the project site, including flood heights and frequency, and current runoff amounts;*	As noted on **Graph 3-2**, three separate flood recharge events have been recorded since 2010 (2010-11, 2013 and 2017), with approximately 65%-75% of annual average rainfall occurring during one month of the year. Relevantly, evidence of flooding following the 2010-2011 flood event was noted during the ALS Water Sciences Group (2011) Baseline Aquatic Survey in June 2011 with debris in trees found 7-8 m above the measured water level at that time (**Section 3.3.4**). Photographic plates and previous stream mapping information to demonstrate the nature of watercourses and drainage lines across the site are presented in **Section 3.3**, including Tooloombah Creek and Deep Creek subject to potential/predicted effects of groundwater drawdown. Other potential influences including tidal fluctuations, storm tides, flood extents and sea level rise have also been considered. **Figures 3-9 and 8-6** demonstrate the extents of storm tide inland and aerial photograph at a low tide (Rosewood Island) respectively.
105	DEE [3, 11, 21s]	• *no consideration of the uncertainty in the regional parameterisation;*	Robust Uncertainty Analysis has been conducted in a systematic manner (**Sections 8.11 and 8.12**) including: parameter identifiability; quantitative UA (**Attachment 11**) including time series plots, probability of exceedance and convergence plots; scenario-based sensitivity analysis (including climate variability / climate change considerations); other qualitative analysis.
106	DEE [3, 11, 21t]	• *the current bore monitoring network is not adequate to understand the nature of the surface water system;*	Alluvial dataloggers have been installed at WMP04 (Tooloombah Creek), WMP05 (Deep Creek) and WMP29A (Styx River) to complement the stream flow gauging stations installed on Tooloombah Creek, Deep Creek and the opportunistic tidal monitoring location at the Ogmore Road Bridge.

Table A1-3 (Continued)
Summary of Department of the Environment and Energy (DEE) Submission Comments [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
107	DEE [3, 11, 21u]	• *the timeframe over which the bores were monitored is not adequate.*	The calibration approach is described in detail in **Section 7.7.1** and the calibration statistics meet AGWM Guideline (**Attachment 10**). Baseline datasets would continue to be augmented in advance and during operations as described in **Section 10.0**.
108	DEE [3, 11, 21v]	*The Department considers the annual water balance is unclear and is contingent on uncertain model inputs (i.e. groundwater flows).*	Groundwater take/inflow predictions based on the improved numerical groundwater model are presented in **Section 8.4**. It is important to note that the modelled average inflow predictions are for accounting purposes and that the actual groundwater inflows reporting to the in-pit sumps (and therefore handled in the site water balance) may be less (or instantaneously more) than those predictions due to a number of factors including potentially enhanced evaporation at the highwall face, actual mine progression and the backfilling sequence (including rate of wetting-up of backfill spoil), etc. The model predicted inflows does not account for direct rainfall or surface water runoff held in storage, nor any pumped water transfers if held in-pit from time to time. Robust Uncertainty Analysis has been conducted in a systematic manner (**Sections 8.11 and 8.12**) including: parameter identifiability; quantitative UA (**Attachment 11**) including time series plots, probability of exceedance and convergence plots (for mine inflows); scenario-based sensitivity analysis (including climate variability / climate change considerations); other qualitative analysis. **Table 8-8** provides a summary of relevant bounds. Refer to separate assessment by WRM Water & Environment (2020).
109	DEE [3, 11, 21w]	*The AEIS does not include an impact assessment of potential flooding of the coal conveyor and its potential impacts on downstream surface water quality, including on the GBRWHA. The proponent notes this impact assessment will be undertaken during the final design of the coal conveyor. The Department considers the inclusion of this assessment in the AEIS is necessary in order for the potential impacts from the proposed action to be understood.*	**Not specifically a Groundwater-Related Matter.** Refer to separate assessment by WRM Water & Environment (2020).
110	DEE [3, 11, 21x]	*The Department considers the AEIS does not adequately demonstrate how the proposed action will have a net benefit for the Great Barrier Reef, as stipulated in the objectives of the Reef 2050 Long-Term Sustainability Plan (2015), and Net Benefit Policy. The proponent has not undertaken calculations, or set parameters or targets, for water quality outcomes for the proposed action.*	**Not specifically a Groundwater-Related Matter.** The Reef 2050 Long-Term Sustainability Plan (2018) is referred to in **Section 2.2.2**. Groundwater quality is described in **Section 5.5**. Refer to separate assessment by WRM Water & Environment (2020) and Fluvial Systems (2020).

Table A1-3 (Continued)
Summary of Department of the Environment and Energy (DEE) Submission Comments [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
111	DEE [3, 11, 21y]	*The Department notes no site investigation of potential acid sulphate soils (PASS) on the project site, particularly within the zone of predicted drawdown, or in the surrounding region, has been undertaken by the proponent to inform an impact assessment on surface water quality. As such, the Department considers the proponent has not adequately demonstrated that the PASS will not impact on surface water quality as a result of the proposed action.*	As concluded in CDM Smith (2018e), the likelihood of disturbing PASS is assessed as low to extremely low probability. Nevertheless, monitoring and management strategies and appropriate contingencies, as outlined in CDM Smith (2018e), would be adopted and implemented should unexpected conditions be encountered.
112	DEE [3, 11, 21z]	*The Department considers the proponent has not provided adequate detail, with supporting evidence, on the proposed construction and management of the final landform to ensure it does not pose an ongoing risk to the downstream environment, including the GBRWHA. The AEIS does not explain how the factors relevant to the final landform (i.e. soil characteristics, landform design, controls, etc.) have been considered to minimise erosion, contamination, and manage dispersive and erosive soil.*	**Not specifically a Groundwater-Related Matter.** An outline of the Mineral Waste Management Plan framework is provided in **Section 10.3.** The potential impacts on groundwater quality during mining and post mine closure is described in **Section 9.2.**
113	DEE [3, 11, 21aa]	*The proponent is proposing to backfill the final voids with coarse and fine coal rejects, which the Department considers will provide an additional source of contaminants that could be mobilised in groundwater. The Department considers the proponent has not adequately addressed this risk in the AEIS, including assessing alternate final landform options.*	Alternative final landform options have been considered by CQCPL and the proposed progressive rehabilitation landform presented in Xenith Consulting (2020). **Sections 8.3.3 and 8.3.4** describe how the in-pit backfilling and emplacement of waste rock and rejects has been considered in the groundwater model and assessment. An outline of the Mineral Waste Management Plan framework is provided in **Section 10.3.** The potential impacts on groundwater quality during mining and post mine closure is described in **Section 9.2.**
114	DEE [3, 11, 21ab]	*The Department considers that just a commitment to develop and implement a Rehabilitation Framework, Progressive Rehabilitation and Closure Plan (PRCP), and ESCP, without providing specific detail to manage impacts, is not adequate.*	**Not specifically a Groundwater-Related Matter.** A draft *Conceptual Erosion and Sediment Control Plan* has been prepared by Engeny Water Management (2020).

Table A1-3 (Continued)
Summary of Department of the Environment and Energy (DEE) Submission Comments [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
115	DEE [2, 14, 21a]	*The Department considers the measures proposed to monitor, mitigate and manage surface and groundwater, sediment and erosion, supplementary flows and the offset site are not adequate to monitor, mitigate and manage the potential impacts of the proposed action on MNES. …*	The proposed monitoring, management, licensing, review and mitigation measures are described in **Section 10.0**. MNES are discussed in **Section 11.1** and offsets in **Section 11.2.** No supplementary water inputs are proposed by CQCPL for the CQC Project, therefore do not require consideration for future groundwater model validation (i.e. as a potential future input to streamflow). However, it is noted that controlled water releases may occur as outlined in WRM Water & Environment Pty Ltd (2020). Record-keeping of such additional water volumes/inputs would be important to inform future groundwater model validation and is relevantly noted as a component of the REMP.
116	DEE [2, 14, 21b]	*The Department considers that a commitment to develop and implement management plans to mitigate and manage potential impacts, without providing specific detail as to the proposed content of the plans, is not adequate.*	An outline of the relevant management plans and the proposed content is provided in **Sections 10.2, 10.3, 10.5 and 10.6**.
117	DEE [2, 14, 21c]	*The Department considers the AEIS does not contain sufficient information regarding the implementation and effectiveness of supplementary flows to manage groundwater drawdown impacts on groundwater-dependent ecosystems (GDEs). …* *Further, the Department considers that a commitment to develop and implement a Receiving Environmental Management Plan (REMP), without providing specific measures to manage impacts on GDEs, is not adequate.*	No supplementary water inputs are proposed by CQCPL for the CQC Project, therefore do not require consideration for future groundwater model validation (i.e. as a potential future input to streamflow). However, it is noted that controlled water releases may occur as outlined in WRM Water & Environment Pty Ltd (2020). Record-keeping of such additional water volumes/inputs would be important to inform future groundwater model validation and is relevantly noted as a component of the REMP.
118	DEE [2, 14, 21d]	*The Department considers key deficiencies of the proposed monitoring framework include:*	Refer below.
119	DEE [2, 14, 21e]	*the baseline surface water quality data is inadequate, and there is no seasonal and inter-annual variability information;*	**Not specifically a Groundwater-Related Matter.** Baseline surface water quality datasets are summarised in **Section 3.2.7**. As demonstrated by the January-February 2020 rainfall events and water quality datasets (**Sections 3.3 and 5.5.7**), the Tooloombah Creek and Deep Creek water quality (salinity) response was clear. Refer to separate assessment by WRM Water & Environment (2020).

Table A1-3 (Continued)
Summary of Department of the Environment and Energy (DEE) Submission Comments [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
120	DEE [2, 14, 21f]	- *no proposed surface water quality monitoring post-closure to monitor erosion of the proposed final landform proposed to comprise sodic and highly erosive soils);*	**Not specifically a Groundwater-Related Matter.** Refer to separate assessment by WRM Water & Environment (2020).
121	DEE [2, 14, 21g]	- *no proposed long-term monitoring to detect potential saltwater intrusion;*	Monitoring is proposed as described in **Sections 6.3.2, 10.1.1 and 10.1.3.**
122	DEE [2, 14, 21h]	- *the proposed long-term surface water quality monitoring is not adequate;*	**Not specifically a Groundwater-Related Matter.** Refer to separate assessment by WRM Water & Environment (2020).
123	DEE [2, 14, 21i]	- *no proposed long-term monitoring of PASS downstream of the project site, including within and outside (i.e. in the intertidal zone) of the predicted zone of groundwater drawdown;*	As concluded in CDM Smith (2018e), the likelihood of disturbing PASS is assessed as low to extremely low probability. Nevertheless, monitoring and management strategies and appropriate contingencies, as outlined in CDM Smith (2018e), would be adopted and implemented should unexpected conditions be encountered.
124	DEE [2, 14, 21j]	- *no proposed monitoring of supplementary flows to assess their effectiveness and success;*	No supplementary water inputs are proposed by CQCPL for the CQC Project, therefore do not require consideration for future groundwater model validation (i.e. as a potential future input to streamflow). However, it is noted that controlled water releases may occur as outlined in WRM Water & Environment Pty Ltd (2020). Record-keeping of such additional water volumes/inputs would be important to inform future groundwater model validation and is relevantly noted as a component of the REMP.
125	DEE [2, 14, 21k]	- *no TARPs (Trigger, Action, Response Plans) have been provided;*	Groundwater level and water quality triggers are described in **Sections 10.1.10 and 10.1.11**. Relevant TARPs for development and finalisation in the management plans are discussed in **Sections 10.2.2, 10.5.2 and 10.6.3**. Orange Environmental is coordinating the preparation of the draft Groundwater Dependent Ecosystem Management and Monitoring Plan and draft Receiving Environment Monitoring Program separately by Eco Logical Australia Pty Ltd (2020b; 2020c). A draft *Conceptual Erosion and Sediment Control Plan* has been prepared by Engeny Water Management (2020).

Table A1-3 (Continued)

Summary of Department of the Environment and Energy (DEE) Submission Comments [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
126	DEE [2, 14, 21l]	- *the proposed upstream locations of surface water monitoring sites are not appropriate because there is only one site for each creek and the data from the sites will be impacted by mine runoff;*	**Not specifically a Groundwater-Related Matter.** Refer to separate assessment by WRM Water & Environment (2020).
127	DEE [2, 14, 21m]	- *the early warning capability of the monitoring network is inadequate;*	The proposed groundwater monitoring network described in **Section 10.1**, annual monitoring review and reporting (**Section 10.7**), and numerical groundwater model review (**Section 10.9**), provides adequate early warning capability. Spatial groundwater levels based on the baseline datasets are discussed in **Section 5.4.1**. **Section 10.0** outlines the proposed groundwater monitoring program, which not unlike other developments similar in nature, would continue to collect baseline datasets to augment the existing datasets, in advance of and during the commencement of mining activities, in support of ongoing validation and monitoring, including review (and reporting) of the numerical groundwater model on a periodic basis. Such monitoring programs and triggers (i.e. TARPs) allow for early detection / trends to enable precautionary and adaptive management to be implemented as and if required, including contingency planning. The numerical groundwater model would be subject to review at least every three (3) years from the commencement of open cut mining, in line with the indicative review timeframes prescribed for UWIRs in Qld. Where additional validation datasets become available and the outcomes of a review were to recommend, the numerical groundwater model may, from time-to-time, be re-calibrated to improve the model performance. At such times, other potential adjustments and/or improvements to the numerical groundwater model could be undertaken, including those identified by peer review. As recommended in **Sections 10.1.9, 10.1.10 and 10.1.11**, ongoing baseline data collected from the installed VWP (north-east) and deep standpipe (east) should continue after mining commences in the west of the tenements, which as demonstrated by the “after 3 years” predicted groundwater drawdown contours, is unlikely to be affected during the initial years of mining based on the sequence proposed. Further to this, it is recommended that a northern (deep) standpipe be installed within six (6) months of commencement of mining activities to provide additional early warning capacity between the CQC Project, historic mine workings at Bowman and west of the mapped fault to validate the depressurisation extents (at depth) in the Styx Coal Measures as it develops. This would allow early validation (or otherwise) of any boundary effects of the fault (as identified during the Uncertainty Analysis) and if any consequential effects were to propagate to the shallower existing groundwater monitoring network. The telemetered stream flow (and pool) gauging stations in Tooloombah Creek and Deep Creek (**Sections 10.1.4 and 10.1.5**), coupled with the continuous alluvial groundwater dataloggers (**Section 10.1.7**), and groundwater pit inflow monitoring program (**Section 10.1.1**) would also provide early warning capability.

Table A1-3 (Continued)
Summary of Department of the Environment and Energy (DEE) Submission Comments [Groundwater-Related] in Relation to the Amended EIS 2019

ID	AGENCY [REF]	AGENCY COMMENT EXCERPT / SUMMARY	RESPONSE
128	DEE [2, 14, 21n]	• *the groundwater monitoring network is inadequate, and there are no compliance or reference bores to the north and/or north-east of the project site to target the Basement aquifer, and no reference bores to the east of the project site to target all aquifers;*	The groundwater monitoring network is described in **Sections 5.1 and 10.1**. A new VWP (WMP31) was installed targeting the basement aquifers to the north-east (and east of the regional mapped fault) targeting the Styx Coal Measures basement (i.e. Permian Measures – Back Creek Group). A new deep standpipe (WMP32^{B}) is also proposed targeting the aquifers to the east. Further to this, it is recommended that a northern (deep) standpipe be installed within six (6) months of commencement of mining activities to provide additional early warning capacity between the CQC Project, historic mine workings at Bowman and west of the mapped fault to validate the depressurisation extents (at depth) in the Styx Coal Measures as it develops. This would allow early validation (or otherwise) of any boundary effects of the fault (as identified during the Uncertainty Analysis) and if any consequential effects were to propagate to the shallower existing groundwater monitoring network.
129	DEE [2, 14, 21o]	• *inconsistency in the long-term monitoring approach of post-mining impacts from the final landform.*	Post-mining groundwater monitoring is described in **Sections 10.1.10 and 10.1.11**. Groundwater (seepage) monitoring is also described in **Section 10.3.1**.
130	DEE [2, 14, 21p]	*Further, the Department considers that a commitment to develop and implement a REMP, Rehabilitation Framework and ESCP to manage impacts on water resources, without the specific details, is not adequate.*	**Not specifically a Groundwater-Related Matter.** The REMP and ESCP framework is outlined in **Section 10.2.1 and 10.6**, with specific details relevant to groundwater. Orange Environmental is coordinating the preparation of the draft Receiving Environment Monitoring Program separately by Eco Logical Australia Pty Ltd (2020c). A draft *Conceptual Erosion and Sediment Control Plan* has been prepared by Engeny Water Management (2020).

Table A1-4
Summary of IESC Assessment Advice [IESC 2018-094] [Groundwater-Related]

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
131	IESC [1]	*The revised groundwater model is inadequate for predicting potential impacts with the required degree of confidence. …* *A high degree of confidence in groundwater modelling and modelling results, including rigorous modelling uncertainty analysis, is required to enable an assessment of the materiality of risks posed by the project.*	As described in **Section 7.9**, the improved numerical groundwater flow model confidence is considered fit for purpose in accordance with the Australian Groundwater Modelling Guidelines (Barnett *et al*., 2012). The overall confidence level classification is considered to be Class 2, and capable of a number of specific uses, and most relevantly is capable of providing estimates of dewatering requirements for mines and excavations and the associated impacts; and is capable of providing impact predictions of proposed developments in medium value aquifers. Uncertainty analysis has been undertaken in accordance with contemporary requirements (IESC Explanatory Note) and the groundwater model and groundwater assessment has been the subject of peer review by AGE Consultants (**Tables A2-4 to A2-6**).
132	IESC [2a]	*The proponent's Class 1 model (as defined in Barnett et al. 2012) is not sufficient for impact prediction for such a high-risk project located within close proximity to a World Heritage Area.*	The location of the GBRWHA is described in **Section 2.2.2**. The Marine National Park Zone MNP-21-1146 (Broad Sound area including the Bedwell Group, Wild Duck and Bamborough Island) is defined in Part 6 of the Great Barrier Reef Marine Park Zoning Plan 2003. The nearest point of the Marine National Park Zone MNP-21-1146 to the Qld coastline is north of Charon Point and Rosewood Island, beyond the north-eastern boundary of the groundwater model domain (**Section 7.4**). **Refer to IESC [1] Response in relation to confidence and the model classification (Attachment 10)**.
133	IESC [2b]	*… modelling needs to be based on representative site-specific data for hydraulic parameters (such as hydraulic conductivity and specific storage), including in deeper layer.*	Representative site-specific data for hydraulic properties has been collected (through aquifer testing [CDM Smith, 2018] and core permeability testwork [GES, 2020]) as described in **Section 5.6**, and combined available literature review and prior modelling provides a basis for numerical groundwater flow modelling which has been tested as part of the Uncertainty Analysis (**Section 8.11 and Attachment 11**). Additional site-specific datasets are presented in **Attachments 7 and 9**.
134	IESC [2c]	*The groundwater model needs to be calibrated with additional data that capture the spatial and temporal variability in hydraulic head.*	Additional datasets have been collected and are summarised in terms of spatial and temporal levels in **Sections 5.4.1 and 5.4.2**. Hydrographs are presented in **Attachment 8**.
135	IESC [3a]	*The IESC also notes that most of the concerns raised in IESC 2017 (Attachment A) relating to the limitations of the groundwater impact assessment and modelling (see IESC 2017 paragraphs 3 and 4 in particular) have not been adequately addressed.*	Refer below.

Table A1-4 (Continued)
Summary of IESC Assessment Advice [IESC 2018-094] [Groundwater-Related]

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
136	IESC [3b]	*IESC 2017 Paragraph 3:* *The proponent acknowledges the limited confidence in the groundwater model and its predicted impacts. The groundwater model requires further development including improved conceptualisation and parameterisation. The proponent should complete the work outlined below.*	Improved conceptualisation is described in **Section 6.0**, and specifically **Section 6.3**. Improved parameterisation is described in **Section 7.0**. **Refer to IESC [1] Response in relation to confidence**.
137	IESC [3c]	*a) Collect site-specific data on a range of hydraulic parameters such as hydraulic conductivity, storativity and recharge to assist with model characterisation and parameterisation.*	Representative site-specific data for hydraulic properties has been collected (through aquifer testing [CDM Smith, 2018; AMEC, 2019] and core permeability testwork [GES, 2020]) as described in **Section 5.6**, and combined available literature review and prior modelling provides a basis for numerical groundwater flow modelling which has been tested as part of the Uncertainty Analysis (**Section 8.11 and Attachment 11**). Additional site-specific datasets are presented in **Attachments 7 and 9**. Storativity and recharge (and ET) estimates are based on to site-specific geology and vegetation cover, considering available literature values. Ranges of recharge are reviewed in the Uncertainty Analysis, and specifically climate change considerations (**Section 8.11.5**).
138	IESC [3d]	*b) Undertake a thorough review of the underlying geological and hydrogeological conceptualisations. There is still uncertainty in these conceptual models which should be addressed through collection of additional site-specific geological and hydrogeological data.*	A thorough review of the underlying geological and hydrogeological conceptualisations has been undertaken and is presented in **Sections 4.0, 5.0 and 6.0**. Supporting site-specific survey and testwork has been undertaken in support of the conceptualisation including TEM survey (**Attachment 5**), and core permeability testwork and VWP installations (WMP31) by GES in 2019.
139	IESC [3e]	*c) Update the groundwater model to fully incorporate a range of possible configurations and dimensions of the final voids so the range of impacts on groundwater can be assessed (discussed further in paragraph 29).*	The transient prediction model includes a range of configurations and dimensions of the open cut mining area as it advances (**Section 8.1**). Results are presented for end of 3 years, 10 years, end of mining (prior to backfill) and post-mining to allow assessment of the range of potential impacts. Notably, as described in **Section 8.9**, the predictive (recovery) model for post mine equilibrium groundwater levels is based on the backfilled final landform (i.e. no final void). The model layer head plots post-mining are presented in **Attachment 15**, and post-mining head gradients shown on **Figures 8-6[a-f]**.
140	IESC [3f]	*d) Implement an additional modelling approach which allows investigation of potential seawater intrusion and seawater inundation (groundwater recharge by saline tidal waters). This will require the use of a variable density groundwater flow and solute simulator such as SEAWAT (USGS 2016).*	**Refer DAF [1.1 & 1.6] & DES [14/32.97].** As demonstrated by the results of the uncertainty (sensitivity) analysis with constant head values of 2 mAHD and higher 4.5 mAHD (i.e. negligible change in the predicted groundwater drawdown extent), the vectors (gradients) during and post-mining remain in the upper layers of the model toward the lower reaches of the Styx River and would therefore not be expected to result in any discernible change in the freshwater-saline water interface as described in **Section 6.3.2**.

Table A1-4 (Continued)
Summary of IESC Assessment Advice [IESC 2018-094] [Groundwater-Related]

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
141	IESC [3g]	*e) Undertake further testing and validation of the groundwater model when suitable data becomes available with predictions regularly checked against ongoing groundwater head observations. A robust criterion should be developed to identify when re-calibration and potentially re-conceptualisation is needed.*	The mechanisms for ongoing review, including annual monitoring review and reporting, and numerical model review (i.e. 3 years following commencement of dewatering activities) to align generally with *Water Act 2000* requirement are prescribed in **Sections 10.7 and 10.9**.
142	IESC [3h]	*f) Obtain a peer-review of the groundwater model as recommended in the Australian Groundwater Modelling Guidelines (Barnett et al. 2012).*	This groundwater model and groundwater assessment has been the subject of peer review by AGE Consultants (2020). Previous peer review have been undertaken by GHD Pty Ltd (2018), HydroAlgorithmics Pty Ltd (2019) and AGE Consultants (2019) (**Tables A2-1 to A2-6**).
143	IESC [3i]	*IESC 2017 Paragraph 4:* *Sensitivity and uncertainty analysis should be used to examine different model parameterisations, model boundary conditions, the effects of applying recharge uniformly versus a more realistic episodic recharge regime, and the likelihood of various impact scenarios. This would assist in understanding and assessing the potential range of changes to the groundwater system and the possible associated ecological impacts. The outputs of these analyses would also be useful to inform management and mitigation options.*	Uncertainty analysis has been undertaken in accordance with contemporary requirements (IESC Explanatory Note) and the groundwater model and groundwater assessment has been the subject of peer review by AGE Consultants (2020). Different model parameterisation and boundary conditions (**Section 7.1.3**) have been considered. Episodic recharge events during the calibration period are discussed in **Section 7.5.4,** and the approach for forward predictions in **Sections 8.2.3 and 8.11.1**. The Uncertainty Analysis outputs are presented in **Attachment 11**.
144	IESC [4]	*The major factors that contribute to the low degree of confidence in the revised model are discussed below*	Refer below.

Table A1-4 (Continued)

Summary of IESC Assessment Advice [IESC 2018-094] [Groundwater-Related]

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
145	IESC [4a]	*a. There are limited time-series data available with which to calibrate and validate the model. Time-series data are available at 18 locations spread across the six layers of the groundwater model according to the calibration hydrographs provided in the Groundwater Technical Report (SEIS, App. 6, Figures 24a, 24b and 24c). Of the available sites, 16 have less than 12 months of data. Most of these sites have five observations made between November 2017 and March 2018. These data are inadequate to characterise the likely seasonal variations in groundwater levels. Additionally, this lack of appropriate seasonal data compromises the model's ability to predict future variability. A baseline dataset of at least two years of contiguous monthly sampling is required and given the seasonal nature of rainfall and the high likelihood of extreme events such as cyclones, even this may not be sufficient. The requirements for baseline data were discussed in IESC 2017.*	Improved calibration and parameterisation has been undertaken including additional groundwater level datasets (historically [2011-2014] and more contemporary [i.e. 2017 to beginning of the 4th quarter 2019]) (**Sections 5.0 and 7.0**). Stream flow datasets have and continue to be collected at gauging stations installed at Tooloombah Creek and Deep Creek with corresponding dataloggers in alluvial groundwater bores. As demonstrated by **Graph 3-2**, and included in the extended calibration datasets, flood (recharge) events resulting from the higher intensity rainfall (including tropical cyclones Tasha [during 2010-2011 flood event], Oswald [during January 2013] and Debbie [during March 2017]) is provided in **Sections 3.3 and 7.5.4**. As described in **Section 7.7.4 (Graph 7-3)**, the long term historical below average rainfall trends can be observed in the model outputs as well as more recently (2018-2019) (**Attachment 8**) with changes in groundwater levels corresponding with below average rainfall periods around the 1960s, 2000s and approaching 2020. As recommended in **Section 10.1**, additional groundwater level monitoring, particularly the monthly suite (select bores) WMP16-WMP30, should continue to augment baseline datasets.
146	IESC [4b]	*b. Despite the completion and testing of several new bores to determine some hydraulic parameters spatial coverage is limited and the groundwater model is mostly constrained by information derived from the shallow aquifers. Further data, preferably from long-term pump tests, are needed for realistic and justifiable model parameterisation (for all parameters and layers). This will improve confidence in model predictions.*	Additional site-specific datasets are presented in **Attachments 7 and 9**. Hydraulic properties based on aquifer testing, literature review and previous modelling is described in **Section 5.6**. Uncertainty analysis has been undertaken in accordance with contemporary requirements (IESC Explanatory Note) and the groundwater model and groundwater assessment has been the subject of peer review by AGE Consultants (2020). As described in **Section 7.9**, the improved numerical groundwater flow model confidence is considered fit for purpose in accordance with the Australian Groundwater Modelling Guidelines (Barnett *et al*., 2012). The overall confidence level classification is considered to be Class 2, and capable of a number of specific uses, and most relevantly is capable of providing estimates of dewatering requirements for mines and excavations and the associated impacts; and is capable of providing impact predictions of proposed developments in medium value aquifers.

Table A1-4 (Continued)

Summary of IESC Assessment Advice [IESC 2018-094] [Groundwater-Related]

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
147	IESC [4c]	*c. The number of bores at which baseline data are collected should also be increased as currently there is insufficient spatial and depth coverage across the groundwater model domain. Monitoring in the Basement aquifer is discussed further in the response to Question 3. When these bores are installed, testing (e.g. pump tests) should be undertaken to provide site-specific measurements of hydraulic parameters which can be used to parameterise the groundwater model.*	Additional datasets have been collected and are summarised in terms of spatial and temporal levels in **Sections 5.4.1 and 5.4.2**. Hydrographs are presented in **Attachment 8** including initial groundwater level/pressure measurements at WMP31. **As demonstrated by the datasets available in Section 5.1, the extensive groundwater monitoring network has a reasonable spatial distribution in the vicinity of the CQC Project, and is made more robust through the installation of the eastern/north-east drill hole(s) targeting the Styx Coal Measures basement (i.e. Permian Measures).** As recommended in **Section 10.1**, additional groundwater level monitoring, particularly the monthly suite (select bores) WMP16-WMP30, should continue to augment baseline datasets. In addition to the above, several additional site-specific groundwater investigations have been undertaken in 2019 to support the groundwater monitoring datasets including: • transient electromagnetic (TEM) survey of groundwater associated with surficial geology (Groundwater Imaging, 2019) (**Attachment 5**); • open end permeability and packer testing at two exploration drill holes STX1901 and STX1902 (AMEC, 2019) (**Attachment 7**); and • core sampling from two exploration drill holes STX1812 and STX1903 and laboratory permeability testing (GES, 2020) (**Attachment 9**).
148	IESC [4d]	*d. Several features and processes that should be incorporated in the groundwater model are either not included or inadequately incorporated. The following need to be included to improve confidence in model predictions.*	The application of key processes is outlined in **Section 8.3**.
149	IESC [4di]	*i. The backfilled voids require appropriate and realistic parameterisation of their hydraulic properties (e.g. hydraulic conductivity of backfilled material will be greater than the undisturbed material). Changes to permeability and specific storage which may occur with consolidation of the waste rock and tailings should also be considered and incorporated into the groundwater model.*	As described in **Section 8.3.3**, the backfilling process is simulated by applying Time-varying Material (TVM) properties to reflect the changes in the host rock properties (pre-mining) to reflect the backfill spoil (broken, less consolidated rock), and was applied generally consistent with the backfill schedule provided. As described in **Section 8.11.2**, ranges and distributions applied to hydraulic properties in the improved numerical groundwater model as part of the quantitative uncertainty analysis (**Attachment 11**) are summarised below: • lognormal distribution with 0.5 standard deviation for $K_{Horizontal}$, S_s and $K_{Horizontal}$/Infiltration% ratio; • truncated lognormal distribution with 0.5 standard deviation for $K_{Horizontal}/K_{Vertical}$ and a minimum of 1 (i.e. to maintain anisotropy greater than 1); and • lognormal distribution with 0.25 standard deviation for S_y. Whilst the calibration process did not enforce depth-dependence (except in initial values and min/max parameter value bounds) the quantitative UA (**Section 8.11.2**) did explore varied coal seam permeability values.

Table A1-4 (Continued)
Summary of IESC Assessment Advice [IESC 2018-094] [Groundwater-Related]

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
150	IESC [4dii]	*ii. All surface water features must be included, whether natural or constructed for the project (e.g. dams and leakage from these). Surface water-groundwater connectivity is a key component of the hydrological, hydrogeological and ecological systems at the project site. There is large uncertainty on the influence of groundwater discharge on surface water flows as no site-specific information has been derived for streamflows in the catchment (see paragraph 6 below).*	**Section 8.3** of the Groundwater Assessment describes the application for key processes and supporting justification for consideration of water storage dams in **Section 8.3.5**. **Modelled groundwater connectivity with watercourses are also discussed in Sections 7.5.3 and 7.7.6, considering the available hydrological datasets presented in Section 3.3.** Refer to separate assessments by Eco Logical Australia (2020a; 2020d).
151	IESC [4diii]	*iii. Potential hydraulic loading impacts from the waste rock dumps must be considered. Understanding how this process could affect groundwater discharges to GDEs and alter groundwater flow paths and groundwater quality, including within the backfilled voids, is important for characterising potential impacts to GDEs and long-term surface water quality.*	The application for key processes are outlined in **Section 8.3**, including consideration of hydraulic properties.
152	IESC [4div]	*iv. Current modelling does not predict that groundwater drawdown will occur in areas where seawater may be present. However, given the limitations of the modelling this possibility should be investigated further. This should include collecting further information to inform additional modelling approaches such as field studies to identify the location of the seawater-freshwater interface. Further discussion of monitoring relating to potential seawater intrusion is provided in the response to Question 3. These data are needed to implement the additional modelling approaches (e.g. using SEAWAT) discussed in paragraph 3d of IESC 2017.*	**Refer DAF [1.1 & 1.6] & DES [14/32.97].** As demonstrated by the results of the Uncertainty Analysis, with constant head values at 4.5 mAHD, the vectors (gradients) during and post-mining remain in the upper layers of the model toward the lower reaches of the Styx River and therefore would not be expected to result in any discernible change in the freshwater-saline water interface as described in **Section 6.3.2**. This is also supported by the magnitude of predicted baseflow impacts / enhanced leakage for the Styx River reach in **Section 8.6.1** and supporting Uncertainty Analysis (**Table 8-8**).

Table A1-4 (Continued)
Summary of IESC Assessment Advice [IESC 2018-094] [Groundwater-Related]

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
153	IESC [4e]	*e. While sensitivity and uncertainty analysis has been undertaken it is inadequate given the high risks associated with the project. The analysis is primarily a sensitivity analysis. The analysis was not undertaken in a rigorous and systematic manner and there is insufficient justification provided for the range of parameter values examined. Further model improvements as outlined above are required and then a rigorous sensitivity and uncertainty analysis will be needed. Given the high risks from the project, this analysis should objectively quantify uncertainty and examine the correlation between parameters, likelihoods and parameterisations that are representative of the natural variability. Additionally, as discussed in paragraph 4 of IESC 2017, this analysis should examine a broader range of model parameterisations, model boundary conditions and episodic versus periodic recharge.*	Robust Uncertainty Analysis has been conducted in a systematic manner (**Sections 8.11 and 8.12**) including: parameter identifiability; quantitative UA (**Attachment 11**) including time series plots, probability of exceedance and convergence plots; scenario-based sensitivity analysis (including climate variability / climate change considerations); and other qualitative analysis.
154	IESC [4f]	*f. An independent peer review of the groundwater model has not been reported. This review should be undertaken as recommended by the Australian Groundwater Modelling Guidelines (Barnett et al. 2012). This was highlighted in paragraph 3f of IESC 2017.*	This groundwater model and groundwater assessment has been the subject of peer review by AGE Consultants (2020). Previous peer review have been undertaken by GHD Pty Ltd (2018), HydroAlgorithmics Pty Ltd (2019) and AGE Consultants (2019) (**Attachment 2**).
155	IESC [5]	*The key risks identified in IESC 2017 (paragraphs 20-39) remain inadequately addressed with the exception of risks related to the location of the coal conveyor (moved in the current plan) and the pit lakes (backfilled in the current plan). Changes in the mine plan have altered the magnitude and nature of key risks and potential impacts associated with surface water and the final landform, and are described below.*	**Not specifically a Groundwater-Related Matter.** The updated backfilled mine plan is described in **Section 8.3.3**.

Table A1-4 (Continued)
Summary of IESC Assessment Advice [IESC 2018-094] [Groundwater-Related]

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
156	IESC [6]	*The surface water modelling of streamflow yields and floods are not supported by any period of local gauging and no consideration is given to the uncertainty in the regional parameterisation. The estimates are considered to have a weak level of defensibility and are insufficient for evaluating impacts on sensitive and high value environmental assets. No advice is provided on the implications of the streamflow yields being towards the lower limits of their associated confidence limits, or flood estimates being towards their upper limits. No attempt has been made to make use of streamflow gauging records in adjacent river basins, either to confirm the applicability of the regional parameters, or to correlate with short-term surface water gauging in the catchments of interest. Given the large uncertainty involved in relying solely on regional information, it is essential that more than one method be used to derive single best estimates of hydrological characteristics (Ball et al. 2016; Nathan and McMahon 2017).*	**Not specifically a Groundwater-Related Matter.** Refer to separate assessment by WRM Water & Environment (2020).
157	IESC [7]	*The coal conveyor location has been revised. It will now follow the Bruce Highway corridor and pass under the highway. The conveyor has not been explicitly included in the flood model. The proponent states that they will undertake assessment of flood immunity at the time of final design (SEIS, Ch. 9, p. 9-150). From maps of flood modelling, the proposed location appears to be subject to flooding that connects to Deep Creek downstream in a 9.5% annual exceedance probability (AEP) event. The risks to downstream water quality from flooding the coal conveyor (or at least around the coal conveyor) must be assessed.*	**Not specifically a Groundwater-Related Matter.** Refer to separate assessment by WRM Water & Environment (2020).

Table A1-4 (Continued)
Summary of IESC Assessment Advice [IESC 2018-094] [Groundwater-Related]

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
158-167	IESC [8-17]	*One of the key surface water risks is release of sediment to the downstream environment, including the Great Barrier Reef World Heritage Area and Marine Park, the Broad Sound Fish Habitat Area, the Styx River Estuary and the riparian habitat of Tooloombah Creek and Deep Creek. The proponent has stated that they will develop an Erosion and Sediment Control Plan (ESCP) (SEIS, Ch. 5, Section 5.11) to manage this potential risk. Given the high likelihood of erosion (and hence sediment release from the project site) due to the prevalence of sodic soils, and the high value and sensitivity of the downstream environment, this plan should be provided before the project progresses to allow an assessment of the adequacy of potential mitigation and management options. The plan should include estimates of the total sediment load (in tonnes) attributable to the project with and without mitigation measures encompassing both typical and flood conditions. Additionally, the seasonal timing and frequency of sediment-laden flows and the characteristics of the entrained sediments (e.g. particle size and chemical composition) should be considered with regards to light and sediment sensitive ecological processes which may be occurring simultaneously (e.g. laying of demersal eggs or recruitment of seedlings). …*	**Not specifically a Groundwater-Related Matter.** Refer to separate assessments by WRM Water & Environment (2020) and Fluvial Systems (2020). The latest Great Barrier Reef Outlook Report 2019 was published by the GBRMPA in 2019 (**Section 2.2.2**). Orange Environmental is coordinating the preparation of the draft Receiving Environment Monitoring Program separately by Eco Logical Australia Pty Ltd (2020c). A draft *Conceptual Erosion and Sediment Control Plan* has been prepared by Engeny Water Management (2020).

Table A1-4 (Continued)
Summary of IESC Assessment Advice [IESC 2018-094] [Groundwater-Related]

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
168	IESC [18]	*Responses to Questions 1 and 2 in this advice cover a number of inadequacies in the assessment of impacts. Additionally, many of the inadequacies in the impact assessment noted in the response to Question 1 of IESC 2017 remain unaddressed. As potential impacts have not been adequately characterised, it is not possible to fully evaluate the effectiveness of potential monitoring and mitigation measures. This is further hampered by the general lack of detailed descriptions of proposed management and mitigation measures (e.g. management plans) and the absence of evidence to support an assessment of their likely effectiveness.*	Noted and now described in **Section 10.0**.
169	IESC [19]	*Any significant groundwater drawdown beneath Deep Creek or Tooloombah Creek would be highly detrimental to GDEs. For example, the loss of groundwater discharge to permanent pools will adversely impact likely important refugia for aquatic species during the dry season. These refugia would provide crucial sources of colonists when flows resume, as has been observed in other dryland rivers (e.g. Perkin et al. 2015). Additionally, drawdown in the alluvial aquifer will reduce the vertical extent of known stygofauna habitat by approximately 90% (SEIS, Ch. 10, Table 10-66). The IESC has little confidence in the proponent's predictions of the magnitude of expected groundwater drawdown impacts, due to deficiencies in groundwater modelling discussed in the response to Question 1.*	As described in **Section 7.9**, the improved numerical groundwater flow model confidence is considered fit for purpose in accordance with the Australian Groundwater Modelling Guidelines (Barnett *et al*., 2012). The overall confidence level classification is considered to be Class 2, and capable of a number of specific uses, and most relevantly is capable of providing estimates of dewatering requirements for mines and excavations and the associated impacts; and is capable of providing impact predictions of proposed developments in medium value aquifers. Predicted groundwater drawdown on springs, wetlands and GDEs are discussed in **Section 8.7.2.** The model predicted baseflow impacts / enhanced leakage are discussed in **Section 8.6**. The quantitative Uncertainty Analysis is presented in **Section 8.11.2** and key aggregate metrics are presented in **Table 8-8** to provide an indication of the magnitude of differences for the changes in baseflow / enhanced leakage estimates, and corresponding probabilities. Refer to separate assessments by WRM Water & Environment (2020) and Eco Logical Australia (2020a; 2020d).
170	IESC [20]	*The proponent has proposed to manage these impacts through supplementary flows. Insufficient information about supplementary flows has been provided. …*	No supplementary water inputs are proposed by CQCPL for the CQC Project, therefore do not require consideration for future groundwater model validation (i.e. as a potential future input to streamflow). However, it is noted that controlled water releases may occur as outlined in WRM Water & Environment Pty Ltd (2020). Record-keeping of such additional water volumes/inputs would be important to inform future groundwater model validation and is relevantly noted as a component of the REMP.

Table A1-4 (Continued)
Summary of IESC Assessment Advice [IESC 2018-094] [Groundwater-Related]

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
171	IESC [21]	*The proposed monitoring framework as presented in the supplementary EIS is not adequate to identify and monitor impacts, or to trigger suitable management measures. IESC 2017 discussed a number of improvements to monitoring and management which require implementation during operational and post-closure phases (see IESC 2017 paragraphs 42d-f, 44-48 and 54-56). These have not been adequately addressed.*	The proposed groundwater monitoring framework, including staged installation and baseline and compliance monitoring is described in **Sections 10.1 and 10.10**.
172	IESC [22]	*Plans that detail monitoring and management measures for both operational and post-closure phases, including restoration and final landform monitoring and management, are critical. These plans provide the information needed to ensure appropriate management measures are available, identified and implemented and should cover both short-term and potential legacy risks. Given the high risks associated with this project, such plans (which have not been provided) are needed during the assessment phase of this project so it can be determined if potential risks from the project can be adequately mitigated.*	Groundwater level and water quality triggers are described in **Sections 10.1.10 and 10.1.11**. Relevant TARPs for development and finalisation in the management plans are discussed in **Sections 10.2.2, 10.5.2 and 10.6.3**. Orange Environmental is coordinating the preparation of the draft Groundwater Dependent Ecosystem Management and Monitoring Plan and draft Receiving Environment Monitoring Program separately by Eco Logical Australia Pty Ltd (2020b; 2020c). A draft *Conceptual Erosion and Sediment Control Plan* has been prepared by Engeny Water Management (2020).
173	IESC [23]	*As was discussed in paragraphs 40, 43 and 47 of IESC 2017, no detail has been provided about any potential trigger action response plans (TARPs) or similar adaptive management approaches for managing impacts on groundwater, surface water, GDEs or the final landform. Due to the high risks associated with the proposed project's location next to sensitive and high-value ecological assets, these plans should be presented during the assessment phase.*	Groundwater level and water quality triggers are described in **Sections 10.1.10 and 10.1.11**. Relevant TARPs are discussed in **Sections 10.2.2, 10.5.2 and 10.6.3**. Orange Environmental is coordinating the preparation of the draft Groundwater Dependent Ecosystem Management and Monitoring Plan and draft Receiving Environment Monitoring Program separately by Eco Logical Australia Pty Ltd (2020b; 2020c). A draft *Conceptual Erosion and Sediment Control Plan* has been prepared by Engeny Water Management (2020).

Table A1-4 (Continued)
Summary of IESC Assessment Advice [IESC 2018-094] [Groundwater-Related]

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
174	IESC [24]	*The proposed locations of the upstream monitoring sites (reference sites) are not appropriate. Only one site is proposed on each of Tooloombah Creek and Deep Creek. As stated in paragraph 46 of IESC 2017, these sites may be affected by runoff from the mine and should be relocated further upstream. Given the high value and sensitivity of the receiving environments, having only one reference site on each stream is not considered leading practice; at least three reference sites per creek should be established to provide reliable estimates of spatial variance in water quality and compensate for any losses of a reference site.*	The proposed monitoring locations are described in **Sections 10.1.4 and 10.1.5**.
175	IESC [25]	*The proponent has collected additional baseline water quality data in 2017 and 2018. A longer time-series is required to capture seasonality and interannual variability and needs to include baseline data at all reference sites (noting comments in the above paragraph regarding their location and number). These data will assist in the development of site-specific water quality guideline values (WQGVs). Site-specific WQGVs should be developed separately for both wet and dry seasons.*	As demonstrated by **Graph 3-2**, and included in the extended calibration datasets, flood (recharge) events resulting from the higher intensity rainfall (including tropical cyclones Tasha [during 2010-2011 flood event], Oswald [during January 2013] and Debbie [during March 2017]) is provided in **Sections 3.3 and 7.5.4**. As described in **Section 7.7.4 (Graph 7-3)**, the long term historical below average rainfall trends can be observed in the model outputs as well as more recently (2018-2019) (**Attachment 8**) with changes in groundwater levels corresponding with below average rainfall periods around the 1960s, 2000s and approaching 2020. As recommended in **Section 10.1**, additional groundwater level monitoring, particularly the monthly suite (select bores) WMP16-WMP30, should continue to augment baseline datasets. The proposed groundwater level and quality triggers are outlined in **Sections 10.1.10 and 10.1.11** and draft EA conditions (for groundwater) included in **Section 10.10**.
176	IESC [26]	*Surface water quality monitoring will need to continue post-closure to monitor for potential impacts from erosion of the final landform. This monitoring plan should consider event-based telemetered surface water quality and continuous flow monitoring in Deep Creek and Tooloombah Creek to identify if changes in water quality are occurring compared to upstream reference sites and during flow events. This should be supplemented with grab samples analysed for a wider suite of parameters (e.g. metals and organics). All of this monitoring should continue post-mining to capture the effectiveness of restoration.*	The telemetered stream flow (and pool) gauging stations in Tooloombah Creek and Deep Creek (**Sections 10.1.4 and 10.1.5**) include water quality parameters (pH and EC).

Table A1-4 (Continued)
Summary of IESC Assessment Advice [IESC 2018-094] [Groundwater-Related]

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
177	IESC [27]	*While the proponent has committed to sediment monitoring (SEIS, Ch. 9, p. 9-78), as the IESC noted previously (IESC 2017 paragraphs 33 and 45c), the proponent should undertake sediment monitoring that is suitable to assess the potential for metal and organics accumulation. No details of parameters proposed to be monitored are currently provided.*	**Not specifically a Groundwater-Related Matter.** Orange Environmental is coordinating the preparation of the draft Groundwater Dependent Ecosystem Management and Monitoring Plan and draft Receiving Environment Monitoring Program separately by Eco Logical Australia Pty Ltd (2020b; 2020c).
178	IESC [28]	*The exposure of Acid Sulfate Soils (ASS) poses a risk to the sensitive and high ecological value downstream environments. The proponent's assessment of risks from ASS is based upon national mapping (SEIS, Ch. 5, p. 5-108). The assessment of risks from potential acid sulfate soils (PASS) or ASS generation within the area of groundwater drawdown needs to be informed by a site-specific investigation undertaken prior to dewatering activities.*	As concluded in CDM Smith (2018e), the likelihood of disturbing PASS is assessed as low to extremely low probability. Nevertheless, monitoring and management strategies and appropriate contingencies, as outlined in CDM Smith (2018e), would be adopted and implemented should unexpected conditions be encountered (**Section 4.4.1**).
179	IESC [29]	*The proponent has presented an indicative management approach for disturbance of PASS/ASS within the disturbed area of the project site (SEIS, Section 5.10.4). No management plan or actions have been described for exposure of PASS/ASS elsewhere as may occur through groundwater drawdown. The proponent needs to provide measures to treat or prevent the exposure of ASS outside of the project disturbance area but within the zone of hydrogeological impact.*	As concluded in CDM Smith (2018e), the likelihood of disturbing PASS is assessed as low to extremely low probability. Nevertheless, monitoring and management strategies and appropriate contingencies, as outlined in CDM Smith (2018e), would be adopted and implemented should unexpected conditions be encountered (**Section 4.4.1**).

Table A1-4 (Continued)
Summary of IESC Assessment Advice [IESC 2018-094] [Groundwater-Related]

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
180	IESC [30]	*According to the proponent, monitoring and management of the final landform are proposed to be undertaken in accordance with the Environmental Management System, which includes a number of intended management plans that will provide restoration goals (SEIS, Ch. 11, p. 11-54). These management plans should consider:*	Refer to **Section 10.2** (including draft ESCP), and Mineral Waste Management Plan (**Section 10.3**).
181	IESC [30a]	• *monitoring for differential consolidation and settlement of backfilled material in the void. This process can affect the hydraulic properties of the backfill. As discussed in paragraph 4d above, realistic representation of the hydraulic properties of the backfill in the groundwater model is needed.*	As described in **Section 8.3.3**, the backfilling process is simulated by applying Time-varying Material (TVM) properties to reflect the changes in the host rock properties (pre-mining) to reflect the backfill spoil (broken, less consolidated rock), and was applied generally consistent with the backfill schedule provided.
182	IESC [30b]	• *monitoring of the final landform using LIDAR or INSAR imagery. This would provide a way to determine elevation changes due to erosion and/or settlement, allowing identification of where repair work may be needed on the final landform.*	As referred to and recommended by Fluvial Systems (2020) **[Attachment 6]**, use of LiDAR imagery could potentially be used for comparison of datasets to inform where repair works may be necessary.
183	IESC [30c]	• *if there is sufficient water of a suitable quality available for irrigation of the initial groundcover and subsequent deep-rooted vegetation on the final landform. Given the local soils are prone to erosion and dispersion, a key requirement in developing the final landform is the rapid initial establishment of preferably locally endemic grass to prevent erosion due to rainfall impact and overland flow during the wet season.*	**Not specifically a Groundwater-Related Matter.**
184	IESC [30d]	• *how to prevent ponding of water on saline sodic soil. High soil salinity, which occurs in some soils at the project site, can mask dispersive behaviour. If the salts are leached due to ponding of water, the soil will become more dispersive and tunnel erosion can be initiated (Dale et al. 2018).*	**Not specifically a Groundwater-Related Matter.**

Table A1-4 (Continued)
Summary of IESC Assessment Advice [IESC 2018-094] [Groundwater-Related]

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
185	IESC [30e]	- *whether any specific treatments of the topsoil applied to the final landform (e.g. lime, mulching) will be required to prevent erosion and allow rapid establishment of vegetation prior to the next wet season and to reduce weed invasion.*	**Not specifically a Groundwater-Related Matter.**
186	IESC [31]	*Areas where spatial coverage must be improved include:* *a. the addition of compliance monitoring and reference bores targeting the Basement aquifer; and,* *b. further reference bores located to the northwest (between RMB09 and RMB10) and to the east of the project (between RMB05 and RMB03) targeting all aquifers.*	The groundwater monitoring network is described in **Sections 5.1 and 10.1**. A new VWP (WMP31) was installed targeting the basement aquifers to the north-east (and east of the regional mapped fault) targeting the Styx Coal Measures basement (i.e. Permian Measures – Back Creek Group). A new deep standpipe (WMP32^{B}) is also proposed targeting the aquifers to the east. Further to this, it is recommended that a northern (deep) standpipe be installed within six (6) months of commencement of mining activities to provide additional early warning capacity between the CQC Project, historic mine workings at Bowman and west of the mapped fault to validate the depressurisation extents (at depth) in the Styx Coal Measures as it develops. This would allow early validation (or otherwise) of any boundary effects of the fault (as identified during the Uncertainty Analysis) and if any consequential effects were to propagate to the shallower existing groundwater monitoring network.

Table A1-4 (Continued)
Summary of IESC Assessment Advice [IESC 2018-094] [Groundwater-Related]

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
187	IESC [32]	*The groundwater monitoring plan needs to explicitly consider monitoring for potential impacts from the final landform including:* *a. regular (preferably at least three-monthly) groundwater quality monitoring down hydraulic gradient of, and close to, the backfilled voids in all aquifers for identification of potential contaminant mobilisation.* *b. groundwater quality monitoring and monitoring for shallow groundwater discharge that may occur where the final landform and the original land surface contact to identify if leaching of contaminants from the ex-pit waste rock dumps is occurring.* *c. monitoring of the alluvial and Styx Coal Measure aquifers where discharge to Tooloombah and Deep Creek is likely to occur. This is needed to identify if hydraulic loading from the waste rock dumps is affecting surface water-groundwater connectivity.*	The proposed groundwater monitoring program is outlined in **Section 10.1**. Additional groundwater level monitoring, particularly the monthly suite (select bores) WMP16-WMP30, should continue to augment baseline datasets. Proposed groundwater (seepage) monitoring is outlined in **Section 10.3.1** for shallow discharge.

Table A1-4 (Continued)
Summary of IESC Assessment Advice [IESC 2018-094] [Groundwater-Related]

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
188	IESC [33]	*Monitoring for potential seawater intrusion is needed. The proponents groundwater modelling indicates that this is unlikely, however, given the low confidence in the current groundwater model this risk cannot be discounted. The monitoring program for seawater intrusion will need to consider the points discussed below.* *a. The current location of the seawater-freshwater interface in different hydrolithologic units will need to be established.* *b. Monitoring will need to include both electrical conductivity (EC) and hydraulic head in different aquifers to allow for density corrections to be made so that groundwater flow directions can be determined (Post et al. 2007). An appropriate approach may consist of a combination of nested bores to monitor hydraulic head and separate bores that are fully screened across their length to measure EC.* *c. Bores must be sited to allow for early warning of seawater intrusion.* *d. Monitoring details, thresholds and effective management responses should be defined in a TARP.*	As described in **Section 6.3.2**, a network of groundwater monitoring bores exists including WMP29A-E, WMP13 and WMP11-11D as well as Landholder Bore 67654 (BH25). The proposed groundwater monitoring program is described in **Section 10.1** and proposed triggers included in **Sections 10.1.10 and 10.1.11.** Alluvial dataloggers have been installed at WMP04 (Tooloombah Creek), WMP05 (Deep Creek) and WMP29A (Styx River) to complement the stream flow gauging stations installed on Tooloombah Creek, Deep Creek and the opportunistic tidal monitoring location at the Ogmore Road Bridge.
189	IESC [34]	*The monitoring bores which are equipped with loggers to monitor groundwater levels daily (currently unclear as to which bores) should also be telemetered so that water levels can be regularly reviewed. This, plus the development and implementation of management triggers for both short-term and long-term groundwater drawdown, will improve the early-warning capabilities of the monitoring network and was noted in paragraphs 42e and 43 of IESC 2017. Daily site-specific rainfall data will also need to be collected to allow interpretation of changes in groundwater levels.*	Alluvial dataloggers have been installed at WMP04 (Tooloombah Creek), WMP05 (Deep Creek) and WMP29A (Styx River) to complement the stream flow gauging stations installed on Tooloombah Creek, Deep Creek and the opportunistic tidal monitoring location at the Ogmore Road Bridge. On-site presence during operations would not require telemetry; therefore groundwater response timeframes would be reviewed as prescribed and triggers developed with appropriate precautionary / adaptive measures (**Section 10.10**). As described in **Section 3.1.1**, the site rainfall gauge can continue to be downloaded as and when required.

Table A1-4 (Continued)
Summary of IESC Assessment Advice [IESC 2018-094] [Groundwater-Related]

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
190	IESC [35]	*If the proposed project progresses, the compliance bores should be monitored more frequently than six-monthly during the first years of mining (i.e. monthly or quarterly depending on the amount of variability identified in the baseline dataset) as these data would be valuable for validation of the groundwater model and re-calibration if required.*	The quarterly monitoring frequency is described in in **Section 10.0** to be generally consistent with requirements for initial years. As recommended in **Section 10.1.1**, additional groundwater level monitoring, particularly the monthly suite (select bores) WMP16-WMP30, should continue to augment baseline datasets.

Table A1-5

IESC Information Guidelines Explanatory Note – Fatal Flaws Review Checklist for Uncertainty Assessment

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
191	IESC-EP [1]	*Is there evidence of engagement ('without prejudice') between the project proponent and regulatory agencies, from the project outset and at subsequent key stages (Figure 3):* • *to discuss and agree on the project objectives and the modelling objectives?* • *to discuss and agree on the uncertainty analysis methodologies, including the nature and scope of the (minimum requirement) qualitative uncertainty analysis, and the quantitative uncertainty analysis for high-risk projects?* • *to review the reporting on the modelling and uncertainty analyses?* • *to agree on justifications of assumptions/criteria applied to implement the methodology?* • *to understand the implications of the results in terms of environmental decision-making?* *to identify whether an independent technical review of the modelling and/or the uncertainty analysis is warranted?*	The past model and assessment history of consultation with regulatory agencies is provided in **Section 7.1.1**. The approach for uncertainty analysis methodologies is outlined in **Section 7.1.3** with reference to qualitative and quantitative approaches in **Sections 8.11 and 8.12**. The chronology of regulatory engagement is evidenced by **Tables A1-1 to A1-4**. Records of briefing meetings with DES is included in **Attachment 17**.
192	IESC-EP [2]	*Is the modelling and uncertainty analysis methodology designed to provide information for decision makers on the effects of uncertainty on the project objectives (echoing the definition of risk in AS/NZS ISO31000:2009) and on the effects of potential bias?*	The approach for modelling and uncertainty analysis methodologies are outlined in **Sections 7.1.2 and 7.1.3** respectively, with reference to qualitative and quantitative approaches in **Sections 8.11 and 8.12**. According to the Risk Management - Principles and Guidelines Standard (AS/NZS) ISO 31000:2009, risk is defined in terms of the effect of uncertainty on objectives, and is recognised in **Section 8.12**.
193	IESC-EP [3]	*Are the adopted conceptual model, complexity–simplicity balance and applied modelling package capabilities commensurate with the overall risk context and the models purpose of investigating the uncertainty/risk issues (i.e. based on the evidence available of engagement identified in item 1)?*	The model conceptualisation is provided in **Section 6.3**. The model complexity and software packages are described in **Section 7.2**.

Table A1-5 (Continued)
IESC Information Guidelines Explanatory Note – Fatal Flaws Review Checklist for Uncertainty Assessment

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
194	IESC-EP [4]	*Has the uncertainty assessment and modelling methodology been designed and implemented using all the available data? Detailed consideration of the hydrological stressors arising from the development and of natural stressors, including climate variability, and unbiased consideration of water-related asset values and causal pathways for potential impacts (direct, indirect and cumulative) should be provided.*	Historic mining data has been used to support model calibration and validation (**Section 7.5.6**) and inform the cumulative assessment (**Section 8.10**). Improved calibration and parameterisation has been undertaken including additional groundwater level datasets (historically [2011-2014] and more contemporary [i.e. 2017 to beginning of the 4th quarter 2019]) (**Sections 5.0 and 7.0**). Stream flow datasets have and continue to be collected at gauging stations installed at Tooloombah Creek and Deep Creek with corresponding dataloggers in alluvial groundwater bores. As demonstrated by **Graph 3-2**, and included in the extended calibration datasets, flood (recharge) events resulting from the higher intensity rainfall (including tropical cyclones Tasha [during 2010-2011 flood event], Oswald [during January 2013] and Debbie [during March 2017]) is provided in **Sections 3.3 and 7.5.4**. As described in **Section 7.7.4 (Graph 7-3)**, the long term historical below average rainfall trends can be observed in the model outputs as well as more recently (2018-2019) (**Attachment 8**) with changes in groundwater levels corresponding with below average rainfall periods around the 1960s, 2000s and approaching 2020. Water-dependent asset values are described generally consistent with Commonwealth databases and draft EV/WQOs (**Section 6.2**). The evapotranspiration rates applied have been set near the Actual ET, and the extinction depths generally consistent with Canadell *et al*. (1996) based on maximum rooting depths of vegetation types and Shah *et al*. (2007) (**Sections 3.1.2 and 7.5.5**).
195	IESC-EP [5]	*Where history-match conditional calibration is undertaken, has it minimised non-uniqueness and error variance (using approaches recommended in the AGMG)? If not, is a reasoned justification provided? Is an acceptable level of model-to-measurement mismatch defined for the conditional calibration?*	The calibration approach is described in **Section 7.7.** A combination of parameter identifiability, sensitivity and qualitative analyses have been used in **Section 8.11** to identify bounds (or constraints) by available observations and then investigate if and/or how such parameters affect the model predictions. This recognises the challenge of non-uniqueness, and the possibility that multiple combinations of parameters may be equally good at fitting historical measurements, but at the same time has been used in support of the combination of parameters applied.
196	IESC-EP [6]	*Are all simulations consistent with all relevant information/data (using approaches recommended in the AGMG)? If not, is a reasoned justification provided?*	The numerical groundwater model simulation period and temporal discretisation is described and justified in **Sections 7.6 and 8.1**.
197	IESC-EP [7]	*Has the model been submitted to stress testing in which a number of extreme parameter combinations (representing a computationally intensive automated conditional calibration or stochastic model evaluation) are tested for model convergence?*	Refer to **Attachment 11**. Robust Uncertainty Analysis has been conducted in a systematic manner (**Sections 8.11 and 8.12**) including: parameter identifiability; quantitative UA (**Attachment 11**) including time series plots, probability of exceedance and convergence plots; scenario-based sensitivity analysis (including climate variability / climate change considerations); and other qualitative analysis. A total of 1,000 model runs were completed with a calibration cut-off of 3% SRMS (i.e. 50% greater than the original transient calibration model).

Table A1-5 (Continued)
IESC Information Guidelines Explanatory Note – Fatal Flaws Review Checklist for Uncertainty Assessment

ID	ADVICE [REF]	ADVICE EXCERPT / SUMMARY	RESPONSE
198	IESC-EP [8]	*Has a parameter sensitivity analysis and/or a parameter identifiability analysis been completed to identify which parameters can be constrained by the available observations and which parameters affect the simulations the most? Are the implications discussed?*	Yes. Refer to **Sections 8.11.1, 8.11.3 and 8.12**.
199	IESC-EP [9]	*Have all reports been prepared in an open, honest and transparent way that is:* • *open to independent scrutiny and not prone to misinterpretation.* • *based on agreed and transparent model objectives.* • *tailored to decision-makers' needs (focusing on messages relevant to their decisions).* *presented in plain and clear language (precise, jargon-free, calibrated), with useful graphics.*	This document. As above [1]-[8]. This groundwater model and groundwater assessment has been the subject of peer review by AGE Consultants (2020). Consultation was undertaken with DES as described in **Section 7.1.3** and record provided in **Attachment 17.** This report has been tailored to respond to the regulator feedback and commentary (**Tables A1-1 to A1-4**).

ATTACHMENT 2
HYDROGEOLOGICAL PEER REVIEW RECONCILIATION TABLES AND FINAL PEER REVIEW LETTER

Table A2-1
Summary of GHD Pty Ltd Independent Third-Party Review Comments [20 December 2018]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
1	GHD [1]	*The model meets the requirements of a Class 1 model. Class 2 is seldom achievable given length of monitoring required to the duration of required post-closure modelling.*	An independent peer review of the improved numerical groundwater model by HydroAlgorithmics (2020) has been completed by AGE Consultants (**Tables A2-4 to A2-6**). Refer to **Attachment 10** with justification for the updated model classification with improvements (including additional groundwater datasets and extended calibration periods).
2	GHD [2]	*The requirements for water level impact assessment during mining and recovery are met, but inflow predictions are less reliable due to the lack of flow data for calibration, other than qualitative observations that creeks do not flow in the dry season.*	As described in **Section 3.3**, stream gauges have been installed on Tooloombah Creek and Deep Creek. As described in **Section 5.1.1**, dataloggers have also been installed at alluvial monitoring bores in the vicinity of the stream gauges. As described in **Section 7.5**, river stage levels have been applied as opposed to flow data for calibration. This was further considered by AGE Consultants (**Table A2-4**) and is discussed separately. Subsequent validation has been completed and presented in **Section 7.8.1**. It is noted that during the extended model calibration period, flood recharge events have been considered associated with high rainfall datasets corresponding with the 2010-11 flood events, and Cyclone Oswald & Cyclone Debbie (**Graphs 3-2 and 7-3**). In terms of reliability of groundwater inflow predictions, the uncertainty analysis has considered a range of scenarios and is described in **Section 8.12**. It is also important to note that the inflow predictions are for licensing purposes and that the actual groundwater inflows reporting to the in-pit sumps may be less than those predictions due to a number of factors including potentially enhanced evaporation at the highwall face, mine progression and wetting up of backfill waste rock emplacement, etc. It is noted that the proportion of predicted groundwater inflows from the coal seams is expected to be higher than those from the interburden, overburden and overlying Cenozoic sediments, and consistent with the findings of the packer testing by AMEC (2019) (**Attachment 7**), the potential for connectivity between surface water flows to groundwater levels in the coal measures at the CQC Project is limited.
3	GHD [3]	*The use of isotropic hydraulic conductivity in the calibrated model is not consistent with general practice, but is addressed in sensitivity analyses as discussed below. …* *The reference used in the report to justify isotropic conditions (Massarotto et al 2003) is related to individual coal seams rather than regional coal measures. This has, however, been addressed by introducing vertical anisotropy in the sensitivity analysis stage, which suggests isotropic conditions overestimate drawdown and are hence conservative.*	As described in **Section 7.4**, the updated model layers have been separated and aggregated. The hydraulic parameters applied are based on a review of aquifer testing, literature and prior modelling in **Section 5.6**. Modelled hydraulic properties are described in **Section 7.7.3** and includes vertical anisotropy. AGE Consultants have confirmed that the model layer separation is a positive development and is discussed separately (**Table A2-4**).

Table A2-1 (Continued)
Summary of GHD Pty Ltd Independent Third-Party Review Comments [20 December 2018]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
4	GHD [4]	*Where there is uncertainty in calibration and some parameters, they are suitably covered by the "breaking-point" assessment.*	Robust uncertainty analysis, including parameter identifiability analysis is now described in **Sections 8.11 and 8.12**. Outputs from the Uncertainty Analysis are presented in **Attachment 11**.
5	GHD [5]	*It is generally satisfactory, although there is room for improvement in mid-elevation areas and matching of transient water levels. Calibration to flow would improve inflow confidence and limit non-uniqueness issues with K and recharge combinations. The large range of elevations over the model domain tends to give a misleadingly low scaled RMS, but it is still considered reasonable.*	Steady-state and transient calibration statistics are presented and compared to the AGMG key parameters in **Sections 7.7.4 and 7.7.5**. Opportunities for calibration to stream flow and future validation is discussed in **Section 7.7.6**. Notably, the two observed head values in the far south-west of the groundwater model domain at approximately 300 mAHD were removed from the statistical summaries to avoid bias (i.e. lowering of the %SRMS error).
6	GHD [6]	*Specific yields tend to be at the lower end of the observed range but this will more likely overestimate drawdown impact than underestimate, hence can be considered conservative for this aspect. Low drain flows to the creek are consistent with the general observation of lack of dry season baseflow, but measured flows would improve confidence.*	Specific yields used in the numerical groundwater model are tabulated in **Section 7.7.3**. Effective porosity laboratory measurements were also taken on a representative sub-sample of the stratigraphic column (**Attachment 9**). The average effective porosity was 1.1% (*NB: this is comparable to the maximum Sy values used in the numerical groundwater model discussed in **Section 7.7.3***). As determined by WRM Water & Environment (2020), the preliminary flow duration curves for Tooloombah Creek and Deep Creek suggest very low (<0.1 ML/day) to no flow occurs for more than 80% of the time (**Sections 3.3.3 and 3.3.4**). Periodic sampling of surface water monitoring sites since mid-2019 also recorded dry reaches.
7	GHD [7]	*A wide range of combined parameters have been used to address calibration limitations.*	Robust uncertainty analysis is described in **Sections 8.11 and 8.12**. Outputs from the Uncertainty Analysis are presented in **Attachment 11**.
8	GHD [8]	*Uncertainty has been noted and has been addressed with sensitivity and breaking-point analyses.*	Robust uncertainty analysis is described in **Sections 8.11 and 8.12**. Outputs from the Uncertainty Analysis are presented in **Attachment 11**.
9	GHD [9]	*The model is suitable for assessing risks of impact from water level changes and relative changes in stream flows, but inflow estimation confidence is lower.*	Model confidence is presented in **Section 7.9** and includes a peer review of the Confidence Level Classification (**Attachment 10**).
10	GHD [10]	*As with all models there is potential to improve the calibration and parameterisation as additional data become available, including groundwater level data in additional areas and over longer time periods, streamflow data and longer-term pumping tests, if practicable.*	Improved calibration and parameterisation has been undertaken including additional groundwater level datasets (historically [2011-2014] and more contemporary [i.e. 2017 to beginning of the 4th quarter 2019]) (**Sections 5.0 and 7.0**). Stream flow datasets have and continue to be collected at gauging stations installed at Tooloombah Creek and Deep Creek with corresponding dataloggers in alluvial groundwater bores.
11	GHD [11]	*2.3.3 groundwater usage (pumping, returns etc) – Only mine extraction in predictions.*	Application for key processes in the predictive model are described in **Section 8.3**. Historic workings for the pre-calibration period and other landholder usage are considered in **Sections 3.4 and 5.2**.

Table A2-1 (Continued)
Summary of GHD Pty Ltd Independent Third-Party Review Comments [20 December 2018]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
12	GHD [12]	*2.3.4 evapotranspiration – Extinction depth possibly shallow but unlikely to impact on model*	The evapotranspiration rates applied have been set near the Actual ET, and the extinction depths generally consistent with Canadell *et al*. (1996) and Shah *et al*. (2007) based on maximum rooting depths of vegetation types (**Sections 3.1.2 and 7.5.5**) to 8 m. Subsequent sensitivity analysis (**Section 8.11.6**) confirms depth is of no consequence where depth to groundwater is greater than extinction depth. .
13	GHD [13]	*2.5.1 baseflow in rivers – Not available.*	As discussed in **Section 5.4.2**, since the installation of dataloggers in WMP04, WMP05 and WMP29A and the gauging stations on Deep Creek and Tooloombah Creek in September/October 2019 there was not a rainfall event of significance to record a response in the shallow groundwater levels for the calibration period. Continued baseline data collection at the gauging stations and alluvial groundwater monitoring bores will allow future validation of the groundwater model. Nevertheless, the groundwater model has quantified predicted changes in modelled baseflows in the watercourse reaches as described in **Section 8.6**.
14	GHD [14]	*2.6.2 spatial variability/heterogeneity of parameters – By layer only.*	**Section 8.3.3** describes the time-varying properties for backfill spoil. The pilot point properties spatial plots are presented in **Attachment 12**.
15	GHD [15]	*2.6.3 interpolation algorithm(s) and uncertainty of gridded data? – Inverse distance weighted*	Described in **Sections 7.2.2, 7.2.3 and 7.2.4**. The CQC Project numerical groundwater model has been developed using MODFLOW-USG (UnStructured Grid). HydroAlgorithmics' AlgoMesh software has been used to generate the mesh for the UnStructured Grid for MODFLOW-USG. The numerical groundwater model was run with USG-Transport (Panday, 2019), an advanced version of the MODFLOW-USG code, using its Sparse Matrix Solver (SMS) package for the iterative numerical solution. Measurement error and data uncertainty is discussed in **Section 8.12.3**.
16	GHD [16]	*2.8.1 Is there a graphical representation of the conceptual model? Does not indicate external boundary conditions*	The Simplified Hydrogeological Units Conceptual Model - West-East Cross Section Schematic is presented in **Figure 6-1** and described in **Section 6.0**, consistent with **Section 7.5.1.** A regional conceptualisation, conceptualisation for model layers and graphical representation for eco-hydrogeological models are also presented in **Figures 6-2 to 6-5.**
17	GHD [17]	*2.10 Have alternative conceptual models been investigated? To some extent in sensitivity analysis*	Reference to the CDM Smith (2018) conceptual model is provided in **Section 6.0**.
18	GHD [18]	*3.3.5 Is the vertical discretisation appropriate? Are aquitards divided in multiple layers to model time lags of propagation of responses in the vertical direction? Limited vertical discretisation but time lags are not critical given the model timescales.*	Separation and aggregation of model layers are described in **Section 7.4**.
19	GHD [19]	*3.4.3 time steps? To be detailed in final draft.*	Stress period lengths are described in **Sections 7.6 and 8.2.2**.
20	GHD [20]	*3.5 Are the boundary conditions plausible and sufficiently unrestrictive? No flow boundaries are in bedrock (except NE) and conservative for drawdown.*	Boundary conditions are described in **Section 7.5**.
21	GHD [21]	*3.5.2 Are the boundary conditions chosen to have a minimal impact on key model outcomes? How is this ascertained?*	Measurable drawdown does not intersect external model boundary, however effects of fault interface (contrasting hydraulic conductivity) evident.

Table A2-1 (Continued)
Summary of GHD Pty Ltd Independent Third-Party Review Comments [20 December 2018]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
22	GHD [22]	*3.5.4 Are lateral boundaries time-invariant? Only internal ET and recharge.*	Refer to **Sections 7.7 and 8.2** which describes the modelled groundwater recharge, initial conditions, stress period lengths and climate application.
23	GHD [23]	*3.6.1 Are the initial heads based on interpolation or on groundwater modelling? Calibrated quasi-steady state (long transient) used for baseline starting heads.*	Initial conditions are described in **Section 8.2.1**.
24	GHD [24]	*3.6.2 Is the effect of initial conditions on key model outcomes assessed? Drawdown graphs show initial conditions were stable before mine impact. Not critical.*	Initial conditions are described in **Section 8.2.1**.
25	GHD [25]	*4.1.2 Flux observations – Flow not available.*	Time series data are now available for two new monitoring sites on the Deep Creek and Tooloombah Creek which suggest zero flow during the extended calibration period toward the end of the extended period of below average rainfall (September-October 2019). This is consistent with absence of pool water sampling opportunities at several locations in Deep Creek which from July 2019 were no longer available during the AMEC (2019) investigations. In January-February 2020, flow data has since been recorded and could be considered in future groundwater model validation. Refer to separate surface water assessment for latest datasets.
26	GHD [26]	*4.1.3 Other: environmental tracers, gradients, age, temperature, concentrations etc. Not available.*	Refer to **Sections 4.3** (TEM Survey), **5.5.8** (environmental isotopes), **6.3.2** (freshwater-saltwater interface – salinity concentrations) and **7.7.4** (vertical head gradients).
27	GHD [27]	*4.2.2 Objective function – Not discussed.*	Refer to **Attachment 11**.
28	GHD [28]	*4.2.3 Identifiability of parameters – Recharge-K couple*	Refer to **Section 8.11.1.**
29	GHD [29]	*4.2.4 Which methodology is used for model calibration? Trial and error then PEST.*	The model calibration approach is described in **Section 7.7**.
30	GHD [30]	*4.3.2 boundary conditions – Recharge only.*	Boundary conditions are described in **Section 7.5**.
31	GHD [31]	*4.3.3 initial conditions – Not critical given pre-mining conditions stable and the long mining and post-closure period modelled.*	Historic mining included to establish initial conditions (**Section 7.5.6**) recognising monitoring locations which could potentially be undergoing recovery e.g. WMP29, WMP11D and WMP10D. Pre-calibration period hydrographs (from 1919) shown on **Graph 7-3**.
32	GHD [32]	*4.4.1 Are there graphs showing modelled and observed hydrographs at an appropriate scale? Some graphs need expanded y-axis.*	Refer to hydrographs in **Attachment 8**.
33	GHD [33]	*4.5 Are multiple methods of plotting calibration results used to highlight goodness of fit robustly? Is the model sufficiently calibrated? Mid-elevation areas not as good but adequate.*	Refer to **Section 7.7 (Graphs 7-1 and 7-2).** Calibration plots showing extrapolated residuals are shown on **Figures 7-7[a-c].**

Table A2-1 (Continued)
Summary of GHD Pty Ltd Independent Third-Party Review Comments [20 December 2018]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
34	GHD [34]	*4.6 Are the calibrated parameters plausible? But at low end of K and Sy range.*	Refer to **Sections 5.6 and 7.7.3**, hydraulic parameters & laboratory core permeability are presented in **Attachment 9**. Ranges also investigated as part of Uncertainty Analysis in **Section 8.11.2**).
35	GHD [35]	*5.5.1 Are the pumping stresses similar in magnitude to those of the calibrated model? If not, is there reference to the associated reduction in model confidence? Limitations discussed, hence Class 1.*	Refer to historic mining (pre-calibration / initial conditions) (**Section 7.5.6**) and Class 2 Model Confidence Classification (**Attachment 10**) (**Tables A10-1 to A10-5**).
36	GHD [36]	*5.5.3 Is the temporal scale of the predictions commensurate with the calibrated model? If not, is there reference to the associated reduction in model confidence? Limitations discussed, hence Class 1.*	The temporal scale of the predictions by comparison to the extended calibration period are outlined in **Table 7-5**, and considered commensurate, Refer to Class 2 Model Confidence Classification (**Attachment 10**) (**Tables A10-1 to A10-5**) and Peer Review **Table A2-5**.
37	GHD [37]	*5.7.2 Does predicted seepage to or from a river exceed measured or expected river flow? Minor creek discharge consistent with observation of no dry season flow*	Refer to **Sections 3.3 and 8.6**. The predicted changes when compared to WRM Water & Environment (2020) derived flow duration curve volumes are very low, and consistent with the observation of very low to no flow for extended periods.
38	GHD [38]	*5.7.3 Are there any anomalous boundary fluxes due to superposition of head dependent sinks (e.g. evapotranspiration) on head-dependent boundary cells (Type 1 or 3 boundary conditions)? Possible combination of drain and ET, but this is OK and both sinks.*	Refer to **Section 7.7.5 and 8.8**. Boundary fluxes and evapotranspiration has been investigated and as shown on **Figures 7-11**, higher fluxes are associated with the furthest north and southern (Tertiary sediments) away from the CQC Project.

Table A2-2 (Continued)
Summary of HydroAlgorithmics Pty Ltd Peer Review Comments [6 January 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
39	HA Supp. [4/1]	*There are no Appendices – they could have been included to hold the aquifer test results, the calibration hydrographs, …*	Previous aquifer test results are presented in Attachment B of Appendix 6 of CDM Smith (2018). The core permeability testwork results and packer testing results are presented in **Attachments 9 and 7** respectively. The calibration hydrographs are presented in **Attachment 8** of this report. The TEM Survey report is included in **Attachment 5** of this report. Layer properties fields are presented in **Attachment 12** of this report. Drawdown prediction figures are presented in **Figures 8-3[a-d]** and **Attachment 14.**
40	HA Supp. [4/2]	*The conceptual model sketch (Figure 10-43) could have been repeated in Document #1 to provide context.*	The Simplified Hydrogeological Units Conceptual Model - West-East Cross Section Schematic is presented in **Figure 6-1** and described in **Section 6.0**, consistent with **Section 7.0**. Additional conceptual model figures are presented in **Figures 6-2 to 6-5.**
41	HA Supp. [4/3]	*There are many cited publications in Document #2 but there is no Reference list.*	The reference list is included in **Section 13.0**.
42	HA Supp. [4/4]	*There are inconsistencies in Document #1 for the definition of model layers.*	The model layers are described in **Section 7.4**.
43	HA Supp. [4/Dot 1]	*Table 1 Document #1 uses numerical footnotes that can be confused with units (e,g. m2/d2 for transmissivity m2/d).*	Symbolic footnotes have been used in the report to avoid confusion.
44	HA Supp. [4/Dot 2]	*Figure 22 Document #1 requires a colour legend.*	Colour legends have been used on report figures.
45	HA Supp. [4/Dot 3]	*Figure 23 Document #1 requires definition of the polarity for the residual.*	Polarity for residuals have been used in the report (**Figure 7-6**).
46	HA Supp. [4/Dot 4]	*What are the floor elevations of the pit? Show on Figure 28 Document #1. [Examination of supplied model files reveals a minimum level of -148 mAHD in the DRN file.]*	The pit floor elevations are described in **Section 8.3.1**, with the deepest drains at -146 to -152 mAHD in Open Cut 2 (east/north-east), and -123 mAHD in Open Cut 1 (north-east).
47	HA Supp. [4/Dot 5]	*On Figure 28 Document #1, does Year 1 (OC1) match Year 7 (OC2)?*	The indicative mine progression / sequencing is described in **Sections 8.1 and 8.3** (**Table 8-1** and **Figure 8-2**).

Table A2-2 (Continued)
Summary of HydroAlgorithmics Pty Ltd Peer Review Comments [6 January 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
48	HA Supp. [4/Dot 6]	*More water level and drawdown contours over the lease should be shown on Figures 29-35 Document #1.*	Water level contours (**Figures 5-3 and 5-4**) and head plots for all model layers have been presented in **Attachment 13.** Model predicted spatial drawdown contours are presented in **Attachment 14** and on **Figures 8-3[a-d] and 8-5[a-d]**.
49	HA Supp. [4/Dot 7]	*Figure 35 requires more detail over the mining footprint to indicate a groundwater sink or mound at equilibrium.*	Recovery groundwater levels in Layers 2, 3, 5, 8, 11 and 12 are presented in **Figures 8-6[a-f] and Attachment 15**. As shown the final landform results in localised mounding beneath the elevated landforms, however in all other areas, groundwater levels effectively recover to pre-mining groundwater levels in the long-term.
50	HA Supp. [4/Dot 8]	*Representative recovery hydrographs should be shown within the mining lease.*	Recovery hydrographs are shown **Graphs 8-3 and 8-4.**
51	HA Supp. [4/Dot 9]	*Page 24 Document #1: streamflow → stream recharge*	Consistent use of terminology has been used for water flow versus recharge in the report.
52	HA Supp. [4/Dot 10]	*Page 24 Document #1: it is unclear whether the stated mm/yr rates are averages of the dynamic monthly rates, or adopted steady state rates.*	The modelled groundwater recharge rates are outlined in **Section 7.7.2. Sections 3.1.1 and 3.1.2** presents the source rainfall and evaporation / ET data for application of corresponding rates.
53	HA Supp. [4/Dot 11]	*Add average mass balance tables for calibration and prediction.*	Mass balance closure errors for calibration and prediction are presented in **Sections 7.7.5 and 8.8.1**.
54	HA Supp. [4/Dot 12]	*Also report peak ML/day or ML/year for Figures 56-57 Document #1 for licensing purposes.*	The model predicted groundwater take / direct inflows to the open cut mining areas are presented in **Table 8-3** as daily averages for an average annual period for licensing purposes. The model predicted groundwater take / direct inflows are also presented on **Graph 8-1**, as daily averages for operational life of the CQC Project (2020-2038) for quarterly intervals based on the configured groundwater model mine sequence.
55	HA Supp. [4/Dot 13]	*Figures 68-69 in Document #1 are incorrectly labelled as "drawdown".*	Use of the term drawdown and depressurisation have been used consistently in the report.
56	HA Supp. [4/Dot 14]	*There is no comment on whether the waste rock stockpiles might cause water quality impacts.*	Geochemical abundance and geochemistry testwork results are summarised in **Section 4.5**. The application for key processes is discussed in **Sections 8.3.2 to 8.3.4** and potential impacts on groundwater quality in **Section 9.2**, with reference to the environmental values in **Section 6.2**.
57	HA Supp. [5/1]	*Bores responsive to streamflow or flood recharge would benefit from sampling more frequently than monthly.*	As described in **Section 5.0**, sampling occurred more frequently at select groundwater bores in 2019 (CQCPL, 2019; AMEC, 2019), however no streamflow or flood recharge events occurred at the time. Alluvial dataloggers were subsequently installed at WMP04, WMP05 and WMP29A.

Table A2-2 (Continued)
Summary of HydroAlgorithmics Pty Ltd Peer Review Comments [6 January 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
58	HA Supp. [5/2]	*At least one groundwater monitoring site close to a stream gauge should be data-logged.*	Alluvial dataloggers have been installed at corresponding locations in the vicinity of the Tooloombah Creek Gauging Station (WMP04) and Deep Creek Gauging Station (WMP05). The suitability of the groundwater monitoring bores was reviewed by GES, including consideration of preliminary results of the TEM survey. Additional dataloggers installed at WMP29A and WMP06.
59	HA Supp. [5/3]	*It is noted that seven of the monitoring bores are screened across the alluvium and coal measures – this is not good practice, as the separate responses would be confused. This also compromises aquifer testing at those sites [Table 10-9 Document #2].*	Aquifer testing results are presented in **Section 5.6**. It is noted that several (WMP04D, WMP06, WMP12, WMP13, WMP20, WMP21D, WMP27) of the 31 groundwater monitoring locations are screened across the two hydrogeological units (e.g. alluvium, regolith and/or coal measures) which does not allow separate responses to be investigated, nevertheless have been considered.
60	HA Supp. [5/4]	*The cause-and-effect analysis has not attempted to distinguish between flood recharge and rainfall recharge as potential causes for observed rises in alluvial water levels. All responsive bores appear to be close to creeks, but this is not stated.*	Temporal groundwater levels and historical trends are presented in **Section 5.4.2**. Rainfall and flood recharge is discussed in **Section 7.5.4**. Alluvial dataloggers have been installed at corresponding locations in the vicinity of the Tooloombah Creek Gauging Station (WMP04) and Deep Creek Gauging Station (WMP05). Additional opportunities identified at WMP06 for future flood recharge events, measured responses and model validation.
61	HA Supp. [5/5]	*There is no comment on whether any landholder bore usage causes a distinct response at any groundwater monitoring bore. None is apparent.*	Landholder bore use is described in **Section 5.2.3**, specifically noting BH20, and adjacent BH16 and BH01X.
62	HA Supp. [5/6]	*This reviewer does not agree with statements in Section 10.7.1.5 [Document #2] on the significance of hydraulic loading caused by waste rock piles. The posited "reduction in hydraulic conductivity and storage capacity of shallow aquifers" would be immaterial, and the idea of a "flow barrier" is not supported, unless the author is referring to development of a groundwater mound within the stockpile.*	Out-of-pit emplacement of waste rock and coal rejects is discussed in **Section 8.3.2**.
63	HA Supp. [5/7]	*The report does not make clear how many of these bores are existing. While the recommended bi-annual monitoring frequency is sufficient for water chemistry, it is not appropriate for water level measurement.*	The existing groundwater monitoring bore network is described in **Section 5.0** and installation details tabulated in **Attachment 4 (Table A4-1).** Quarterly (and select data-logged) monitoring frequency is proposed as described in **Sections 10.1 and 10.10 (Table 10-7)**.
64	HA Supp. [6/1]	*Aggregating coal seams with interburden prohibits the modeller from applying separate coal and rock permeabilities based on experience. If coal seams are well defined, it would be better to represent them as separate layers.*	Separation and aggregation of model layers has been applied in the numerical model as described in **Section 7.4.1**.

Table A2-2 (Continued)
Summary of HydroAlgorithmics Pty Ltd Peer Review Comments [6 January 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
65	HA Supp. [6/2]	*The layer holding the coal seams (Layer 4 in Table 2) should have higher lateral hydraulic conductivity (Kh) than the coal measures layers above and below.*	Separation and aggregation of model layers has been applied in the numerical model as described in **Section 7.4.1**. Hydraulic parameters have been considered and are discussed in **Sections 5.6.4 to 5.6.6**. Modelled hydraulic properties are described in **Section 7.7.3**.
66	HA Supp. [6/3]	*Of concern is the lack of anisotropy between lateral and vertical (Kv) hydraulic conductivity in the adopted properties for the three coal measures layers in Table 4, although some anisotropy was expected in Table 2. Kv should be much lower than Kh, usually by several orders of magnitude. Some evidence for this is expressed in the literature review summarised in Table 10-11 of Document #2. It is presumed that Kh and Kv were incorrectly linked to the same value in PEST calibration. This should be corrected in the next model revision.*	Modelled hydraulic properties are described in **Section 7.7.3** and includes vertical anisotropy.
67	HA Supp. [6/4]	*Another concern with the current model is the failure to represent backfill correctly. This should be given higher permeability and storage properties using the TVM*[42] *package in MODFLOW-USG and higher rainfall recharge (after a period of no recharge until the spoil wets up). As the model assumes layered host properties are reinstated when mine drain cells are deactivated (after one year of mining), the simulated rate of recovery would be too fast. During mining, the hydraulic gradient from a previously mined area to the active pit would be too high, giving exaggerated mine inflows. After mining has finished, the current model would indicate unrealistically rapid recovery to equilibrium conditions.*	As described in **Section 8.3.3**, the backfilling process is simulated by applying Time-varying Material (TVM) properties to reflect the changes in the host rock properties (pre-mining) to reflect the backfill spoil (broken, less consolidated rock), and was applied generally consistent with the backfill schedule provided.
68	HA Supp. [6/5]	*It is noted that no final void modelling has been done because the pits are to be restored to "at least pre-mining ground elevation and there will be no pit void following mine completion". Even with bulking, it is doubtful whether sufficient backfill could be found on-site to achieve this design. If a final void proves necessary, additional modelling would be required.*	The final landform design is described in **Section 8.3.6**. Predictive (Recovery) modelling for post mine closure equilibrium groundwater levels is presented in **Section 8.9**.

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[42] Time-Variant Materials

Table A2-2 (Continued)
Summary of HydroAlgorithmics Pty Ltd Peer Review Comments [6 January 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
69	HA Supp. [6/6]	*Flood recharge has been modelled with the RCH package instead of the RIV package. Either could be used, but it is not clear whether flood recharge is continuous in time or limited to certain months during the calibration period.*	Modelled groundwater recharge during the calibration period is described in **Section 7.7.2**.
70	HA Supp. [6/7]	*Transient calibration would appear "good" from favourable performance statistics (1.7 %RMS; 5.2 mRMS) but the calibration period is very short (15 months), the groundwater hydrographs show little response during that time, and the simulated graphs do not capture well the water level fluctuations when they occur.*	As shown in **Graph 7-3**, calibration datasets were extended and the long term historical below average rainfall trends can be observed in the model outputs as well as more recently (2018-2019) (**Attachment 8**) with changes in groundwater levels corresponding with below average rainfall periods around the 1960s, 2000s and approaching 2020. The groundwater level steady state and transient calibration (observed versus computed groundwater levels) are presented in **Graphs 7-1 and 7-2** and the corresponding performance statistics tabulated in **Table 7-14**. The scaled root mean square (SRMS) error for the transient calibration is 2.01%, where < 10% is the often-used criteria for acceptable model calibration (Barnett et al., 2012) and is discussed further in **Section 7.9** and presented **Attachment 10 (Table A10-4)**.
71	HA Supp. [6/8]	*The sensitivity analysis based on PEST calibration outputs has a surprising result, that low sensitivity is expected for the permeability in the layer that holds the coal seams. As this is likely to be highly sensitive during prediction, the implication is that the monitoring dataset does not have sufficient information content to reveal the effect of the coal seams on the groundwater system.*	Separation and aggregation of model layers has been applied in the numerical model as described in **Section 7.4.1**. Hydraulic parameters have been considered and are discussed in **Sections 5.6.4 to 5.6.6**. Modelled hydraulic properties are described in **Section 7.7.3**. Uncertainty Analysis (including parameter sensitivity analysis) is described in **Section 8.11** and limitations and opportunities discussed in **Section 8.12**.

Table A2-2 (Continued)
Summary of HydroAlgorithmics Pty Ltd Peer Review Comments [6 January 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
72	HA Supp. [6/9]	*A thorough uncertainty analysis has been undertaken by means of PEST null-space monte carlo analysis. Reporting, however, is too brief. There is no information given on the prior or posterior probability distributions, or on what basis 106 of the 129 realisations were selected. The expected correlation between recharge and Kh is explored also, presumably by standard monte carlo techniques. Again, there is no explanation for the winnowing of 77 models from the 100 trials – what calibration criterion was applied? Uncertainty results are presented as minimum and maximum effects. This is too severe. The author dismisses the reported mine inflow extremes as "unrealistic", but these property extremes should have been excised when setting up the probability distributions prior to monte carlo selection. Given the date of Document #1 (May 2018), the modeller might not have been aware of the draft Uncertainty Analysis guide issued by the IESC in February 2018 and now finalised in December 2018. This promotes the use of percentiles rather than minima/maxima.*	Uncertainty Analysis reporting is included in **Sections 8.11** and **8.12** and separate reporting in **Attachment 11**. Use of percentiles has been included to present the outputs in accordance with IESC's *Information Guidelines Explanatory Note: Uncertainty Analysis – Guidance for Groundwater Modelling within a Risk Management Framework* (dated 17 December 2018). Prior and posterior distributions are specifically considered in **Attachment 11**.
73	HA Supp. [6/Dot 1]	*Maximum ET rate should be set near "Actual ET" rather than evaporation.*	The evapotranspiration rates applied have been set near the Actual ET, and the extinction depths generally consistent with Canadell *et al*. (1996) and Shah *et al*. (2007) based on maximum rooting depths of vegetation types (**Sections 3.1.2 and 7.5.5**).
74	HA Supp. [6/Dot 2]	*Adopted alluvium recharge (0.6%) is low.*	As described in **Section 7.7.2**, the moderate initial recharge value (1.3%) of annual rainfall has been applied to the Quaternary Alluvium (Qa and Qhe) units.
75	HA Supp. [6/Dot 3]	*Adopted alluvium specific yield (1%) is very low.*	Specific yields used in the numerical groundwater model are tabulated in **Section 7.7.3**. Effective porosity laboratory measurements were also taken for a on a representative sub-sample of the stratigraphic column (**Attachment 9**). The average effective porosity was 1.1% (*NB: this is comparable to the maximum Sy values used in the numerical groundwater model*).
76	HA Supp. [6/Dot 4]	*Prediction scenarios are not defined; e.g. (1) null; (2) mining; (3) cumulative.*	Model variants (including null, cumulative and project alone) are described in **Table 7-9**.
77	HA Supp. [6/Dot 5]	*If cumulative assessment is not relevant, this should be defended by citing the distance to the nearest mine.*	Cumulative assessment including historic mine working as Ogmore and Bowman is described in **Sections 3.4.5 and 8.10**.

Table A2-2 (Continued)
Summary of HydroAlgorithmics Pty Ltd Peer Review Comments [6 January 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
78	HA Supp. [6/Dot 6]	*Prediction stress period length is not stated. [Examination of supplied model files confirms monthly stress period duration.]*	Prediction stress period lengths are stated in **Section 8.2.2**.
79	HA Supp. [6/Dot 7]	*Recovery stress period lengths are not stated. [Examination of supplied model files confirms 12 monthly stress periods, then 30 10-year stress periods followed by two 100-year stress periods.]*	Recovery stress period lengths are stated in **Section 8.2.2**. As provided in **Table 7-1**, the stress period lengths for the predictive model range from monthly (for mine prediction and mine closure) to annual (for post-mining), five yearly (to 100 years post mining) and 400 years (for long-term post-mining recovery).
80	HA Supp. [6/Dot 8]	*Outer drawdown contours are 0.1 m and 1 m. While 0.1 m is instructive for effects on GDEs, it is beyond the accuracy of modelling. A 2 m contour is preferred to 1 m, as that is the Queensland Water Act criterion for the impact threshold for alluvium.*	Groundwater drawdown contours are presented clearly on plots to 2 m for unconsolidated aquifer and 5 m for consolidated aquifers as discussed in **Section 8.5**. These intervals are consistent with the bore trigger thresholds defined in the *Water Act, 2000*.
81	HA Supp. [6/Dot 9]	*Mining effects on baseflow and ET are combined but should be separated, as the former is licensable (within the mine lease) and the latter is not.*	Predictive model baseflow impacts / enhanced leakage are described separately in **Section 8.6**. Effects of enhanced recharge on backfill to be described in **Section 8.3.3**. Groundwater licensing requirements are described in **Section 10.4**.
82	HA Supp. [6/Dot 10]	*Model confidence class should be defended by marking applicable attributes in the manner advocated in the IESC Explanatory Note on Uncertainty Analysis.*	The numerical groundwater model review of confidence level checklists are included in **Attachment 10** and have been augmented based on the IESC's Information Guidelines *Explanatory Note: Uncertainty Analysis – Guidance for Groundwater Modelling within a Risk Management Framework* (dated 17 December 2018) and discussed in **Section 8.12**.
83	HA Supp. [7/1]	*Vertical hydraulic conductivity in the coal measures should be much lower than horizontal hydraulic conductivity; at present they are assumed equal.*	Separation and aggregation of model layers has been applied in the numerical model as described in **Section 7.4.1**. Hydraulic parameters have been considered and are discussed in **Sections 5.6.4 to 5.6.6**. Modelled hydraulic properties are described in **Section 7.7.3**, and includes vertical anisotropy.
84	HA Supp. [7/2]	*Backfill should be modelled dynamically with higher hydraulic conductivities; at present the low permeabilities of the host rocks are reinstated.*	As described in **Section 8.3.3**, the backfilling process is simulated by applying Time-varying Material (TVM) properties to reflect the changes in the host rock properties (pre-mining) to reflect the backfill spoil (broken, less consolidated rock), and was applied generally consistent with the backfill schedule provided.

Table A2-2 (Continued)
Summary of HydroAlgorithmics Pty Ltd Peer Review Comments [6 January 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
85	HA Supp. [7/2]	*The time-series data used for model calibration to April 2018 do not have sufficient information content to reliably inform the model during the calibration process.* • *This is partly due to the lengths of record, varying from a minimum of 5 months at four sites to 13 months at one site, and partly due to the wide (~monthly) interval for water level measurement.* • *At least one of the sites responsive to stream or flood recharge should be data-logged continuously.*	Improved calibration and parameterisation has been undertaken including additional groundwater level datasets (historically [2011-2014] and more contemporary [i.e. 2017 to beginning of the 4th quarter 2019]) (**Sections 5.0 and 7.0**). Stream flow datasets have and continue to be collected at gauging stations installed at Tooloombah Creek and Deep Creek with corresponding dataloggers in alluvial groundwater bores (WMP04 and WMP05). As demonstrated by **Graph 3-2**, and included in the extended calibration datasets, flood (recharge) events resulting from the higher intensity rainfall (including tropical cyclones Tasha [during 2010-2011 flood event], Oswald [during January 2013] and Debbie [during March 2017]) is provided in **Sections 3.3 and 7.5.4**. As described in **Section 7.7.4**, the long term historical below average rainfall trends can be observed in the model outputs as well as more recently (2018-2019) (**Attachment 8**) with changes in groundwater levels corresponding with below average rainfall periods around the 1960s, 2000s and approaching 2020. As recommended in **Section 10.1.1**, additional groundwater level monitoring, particularly the monthly suite (select bores) WMP16-WMP30, should continue to augment baseline datasets.
86	HA Supp. [Table 1/ 1.3]	*Is a water or mass balance reported? [Deficient]*	A conceptual water balance is provided in **Section 6.3.7**. The calibration and predictive model mass balance, including closure errors, are presented in **Sections 7.7.5 and 8.8**.
87	HA Supp. [Table 1/ 7.3]	*Is the time horizon for prediction comparable with the length of the calibration / verification period? [No]*	The time horizons for prediction is not excessive when compared with the length of the pre-calibration and calibration periods described in **Section 7.6**.

Table A2-3
Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
88	AGE [1]	***3.1 Data Availability*** *The sources of data are clearly identified in Table 10-3, and these appear to be appropriate for the data listed.*	The sources of additional datasets are referenced in **Sections 3.0 to 5.0 and 13.0**, **Attachment 4** (CQCPL), **Attachment 5** (Groundwater Imaging), **Attachment 7** (AMEC) and **Attachment 9** (GES).
89	AGE [2]	*Many statements are made about understanding the seasonal water level behaviour from the observations, however the available data may not be representative of the 'average' seasonal response. …* *Focusing on the most recent data (which aligns to the available groundwater level data), the indicated trend is average, however it appears to be strongly influenced by the Rockhampton data and not the more local Strathmuir data.*	Specific discussion is included in **Section 3.1.1** including representative BOM (Strathmuir) and site-specific (Mamelon Station) data to describe long-term rainfall trends, flood recharge events (2010-11, Cyclone Oswald and Cyclone Debbie) and average, to below average conditions in the near term. The cumulative rainfall residual is also presented on the hydrographs (**Attachment 8**).
90	AGE [3]	*Ideally, the transient groundwater level data would be over a longer period than this, to provide more confidence in the long-term groundwater behaviour and to put into context the current period of record. This is something that only ongoing monitoring can address, though the limitations of this period and the potential for higher groundwater levels when rainfall deficits reduce should be stated. …*	Improved calibration and parameterisation has been undertaken including additional groundwater level datasets (historically [2011-2014] and more contemporary [i.e. 2017 to beginning of the 4th quarter 2019]) (**Sections 5.0 and 7.0**). Stream flow datasets have and continue to be collected at gauging stations installed at Tooloombah Creek and Deep Creek with corresponding dataloggers in alluvial groundwater bores (WMP04 and WMP05). As demonstrated by **Graph 3-2**, and included in the extended calibration datasets, flood (recharge) events resulting from the higher intensity rainfall (including tropical cyclones Tasha [during 2010-2011 flood event], Oswald [during January 2013] and Debbie [during March 2017]) is provided in **Sections 3.3 and 7.5.4**. As described in **Section 7.7.4**, the long term historical below average rainfall trends can be observed in the model outputs as well as more recently (2018-2019) (**Attachment 8**) with changes in groundwater levels corresponding with below average rainfall periods around the 1960s, 2000s and approaching 2020. As recommended in **Section 10.1.1**, additional groundwater level monitoring, particularly the monthly suite (select bores) WMP16-WMP30, should continue to augment baseline datasets.

Table A2-3 (Continued)

Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
91	AGE [4]	*Water level observations in the alluvium, and to a lesser extent in the shallow Styx Coal Measures (overburden in the report) and weathered regolith show a similar general decline over the period of record as the CDFM. This indicates that the recharge for these areas is rainfall driven and there is connection to what is occurring at the surface. The deeper Styx Coal Measure water level data shows no specific decline, indicating limited connection to surface processes and to the shallow formations.*	Specific discussion is included in **Section 3.1.1** including representative BOM (Strathmuir) and site-specific (Mamelon Station) data to describe long-term rainfall trends, flood recharge events (2010-11, Cyclone Oswald and Cyclone Debbie) and average, to below average conditions in the near term. The cumulative rainfall residual is also presented on the hydrographs (**Attachment 8**).
92	AGE [5]	*3.2 Hydrostratigraphic Units* *The segregated hydrostratigraphic units (HSU) adopted in the conceptual model appear plausible apart from the grouping of coal seams and associated interburden. The model and its predicted impacts would benefit from representing the coal seams as discrete units.*	Separation and aggregation of model layers has been applied in the numerical model as described in **Section 7.4.1**. Hydraulic parameters have been considered and are discussed in **Sections 5.6.4 to 5.6.6**. Modelled hydraulic properties are described in **Section 7.7.3**, and includes vertical anisotropy.
93	AGE [6]	*The coal measure stratigraphy is not indicated within the supplied sections of documents. There is no stratigraphic plot showing the distribution of the coal within the coal measures. The only indication of the coal seam thickness is one mention of one seam 4 m thick (Section 10.5.6.3) that might have influenced aquifer hydraulic testing. …* *Typically, the coal measures would be represented by model layers that represent the coal only, and other model layers that represent the remainder of the layered coal measures (non-coal lithologies such as mudstones, siltstones and sandstones). There are no specific coal seam hydraulic conductivity measures at the project site, however experience shows that coal seams can be up to 1 to 2 orders of magnitude higher in hydraulic conductivity than the adjacent interburden geologies, and it is the coal seams where depressurisation can propagate.*	The coal measure stratigraphy is described in **Section 4.2.1**. Separation and aggregation of model layers has been applied in the numerical model as described in **Section 7.4.1**. Hydraulic parameters have been considered and are discussed in **Sections 5.6.4 to 5.6.6**. Modelled hydraulic properties are described in **Section 7.7.3**, and includes vertical anisotropy. Packer testing datasets from the site are presented in **Attachment 7**. Laboratory core permeability datasets are presented in **Attachment 9**.

Table A2-3 (Continued)
Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
94	AGE [7]	*Coal seam hydraulic conductivity is depth dependent due to the structure of coal and the cleats that provide the permeable nature. There can be a decline in hydraulic conductivity with depth as the cleats close up due to the overburden pressures, however without coal seam specific data it is impossible to know if this is significant in the comparatively shallow coal seams the Project will intercept.*	As described in **Section 6.1.2**, consistent with Coffey (2014) (from field data and testing in the Bowen Basin), depth dependence in coal seams has also been considered for the Styx Coal Measures (**Table 6-4**). **Graph 5-12** presents the approach for the application of a linear reduction in hydraulic conductivity (Kx).
95	AGE [8]	***3.3 Aquifer Parameters*** *The current conceptual model (and subsequent numerical model) assumes that the vertical anisotropy of the coal measures is 1. That is, the horizontal and vertical hydraulic conductivities for the coal measure HSU (including the overburden and underburden) are assigned the same value. Sedimentary layered geologies usually have a lower vertical hydraulic conductivity than horizontal hydraulic conductivity. Representing a series of these sedimentary interburden units in a single model layer usually results in a representative vertical hydraulic conductivity that is at least an order of magnitude lower than the horizontal. In the modelling presented, the significant lumping of differing layered geologies into the three model layers that represent the Styx Coal Measures should be modelled with a vertical hydraulic conductivity of at least 1 order of magnitude less than the corresponding horizontal hydraulic conductivity.*	The coal measure stratigraphy is described in **Section 4.2.1**. Separation and aggregation of model layers has been applied in the numerical model as described in **Section 7.4.1**. Hydraulic parameters have been considered and are discussed in **Sections 5.6.4 to 5.6.6**. Modelled hydraulic properties are described in **Section 7.7.3**, and includes vertical anisotropy. Packer testing datasets from the site are presented in **Attachment 7**. Laboratory core permeability datasets are presented in **Attachment 9**.
96	AGE [9]	*The journal article referenced in Section 3.7.2.2 to support the vertical anisotropy approach is focused on coal seams only and not coal measures. If the model layers were discretely modelling coal seams then an anisotropy approaching 1 would be expected for the coal seam layer, but not the interburden. The adopted anisotropy may be enhancing connectivity with shallow aquifers outside the mining area and potentially leading to an overestimation of shallow drawdown.*	Agreed.

Table A2-3 (Continued)
Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
97	AGE [10]	*Table 10-11 provides a summary of the hydraulic testing undertaken at the site with around 32 bores (11 in alluvium, 19 in Styx coal measures, and 2 in the weathered basement) tested, however there no instances of coal seam only hydraulic conductivity measurements from the site. Most of the testing has focused on the interburden material or combined testing of interburden and coal seams. Specific measurements of coal seam hydraulic conductivity should be taken as this will aid in better estimating the extent of drawdown or depressurisation in the coal seam.*	The coal measure stratigraphy is described in **Section 4.2.1**. Separation and aggregation of model layers has been applied in the numerical model as described in **Section 7.4.1**. Hydraulic parameters have been considered and are discussed in **Sections 5.6.4 to 5.6.6**. Modelled hydraulic properties are described in **Section 7.7.3**, and includes vertical anisotropy. Packer testing datasets from the site are presented in **Attachment 7**. Laboratory core permeability datasets are presented in **Attachment 9.**
98	AGE [11]	*Table 10-11 shows that of the three divisions of HSU2 representing the whole Styx Coal Measures, the middle division that contains the coal seams recorded statistics (minimum and maximum) of hydraulic conductivity that were lower than the units defining the overburden and underburden. The result is unexpected as the coal seams are generally considered the 'aquifers' of coal measure sequences. This is acknowledged in the report, but it considers that this concept is borne out of experience with Permian coal seams, and that the Cretaceous coal seams may differ in this respect.* *The reviewer has also realised how little literature there is on the hydraulic conductivity of the Cretaceous coal seams, and thoughts are therefore turned to the testing undertaken – which is largely rising or falling head tests. Also, there are no tests that have discretely tested the coal seams (without interburden). The reviewer has often found that packer tests provide the best estimate of in-situ hydraulic conductivity for modelling. Lab core testing tend to provide a lower bound and slug tests provide upper bounds. Undertaking packer testing would allow for discrete testing of the coal seams as well, which the reviewer considers is a critical gap in the data collection to date.*	The coal measure stratigraphy is described in **Section 4.2.1**. Separation and aggregation of model layers has been applied in the numerical model as described in **Section 7.4.1**. Hydraulic parameters have been considered and are discussed in **Sections 5.6.4 to 5.6.6**. Modelled hydraulic properties are described in **Section 7.7.3**, and includes vertical anisotropy. Packer testing datasets from the site are presented in **Attachment 7**. Laboratory core permeability datasets are presented in **Attachment 9.**

Table A2-3 (Continued)

Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
99	AGE [12]	*It is acknowledged that the setting of a low specific storage (to compressibility of water) and specific yield will maximise the extent of drawdown with everything else being equal. What doesn't become conservative then is the predicted inflow to the pit. Based on previous experience, the adopted specific yield is also on the low side at 1% for alluvium and 0.5% for all other hydrogeological units. These low values mean that it is possible the take of groundwater from the system is underestimated.*	Specific yields used in the numerical groundwater model are tabulated in **Section 7.7.3**. Effective porosity laboratory measurements were also taken for a on a representative sub-sample of the stratigraphic column (**Attachment 9**). The average effective porosity was 1.1% (*NB: this is comparable to the maximum Sy values used in the numerical groundwater model*). Application of physical upper limit for unconsolidated materials is as determined by Rau *et al.* (2018). However, for the purposes of the uncertainty analysis, the ranges / distributions have not been constrained.
100	AGE [13]	***3.4 Seawater Intrusion*** *Figure 10-34 shows the measured salinity within the study area, and the distribution is confusing at best, with some very high salinities in bores located across the site, and lower salinity values towards the coast. From the available data there is no indication of the interface location. …* *The salinity distribution in Figure 10-34 also highlights uncertainty in the conceptual model.*	A description of tidal influence in the Styx River catchment is provided in **Section 3.3**, including comparison of long term tidal datasets / north and south of Broad Sound (Hay Point and Rosslyn Bay). Analysis of tidal amplitude predictions with datalogger recordings at WMP29A are also provided. Corresponding surface water quality summaries are provided in **Section 3.2.7**, including salinity measurements at the gauging stations on Tooloombah Creek (ToGS01) and Deep Creek (DeGS01). Measured salinities within the study area are provided in **Section 5.5** and have been considered for hydrogeological unit. Specific analysis has been undertaken considering the regional groundwater quality zones in **Section 5.5.9**, and the very high salinity bores (WMP13 and WMP26) are specifically discussed in **Section 6.3.2** to help describe the broad conceptualisation for the freshwater-saline water interface. Opportunistic depth to water surface measurements have and would continue to be taken periodically to validate the range of predicted stage water levels in the Styx River. Verification of the permanent survey marker elevation has also been undertaken by CCS Surveys Pty Ltd (2020) and is discussed in **Section 8.12.3**.
101	AGE [14]	*It is reported that bore water levels have been adjusted for salinity to produce an equivalent freshwater head. There is no detail on the adjustment process (and any associated assumptions) used, nor exactly which bores required the adjustment, and what the adjustment involved. This should be discussed / tabulated in the report.*	SWLs are presented on the hydrographs in **Attachment 8** without adjustment. It is however noted that the broad conceptualisation for freshwater-saline water interface (Ghyben-Herzberg relationship) is described in **Section 6.3.2**.

Table A2-3 (Continued)
Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
102	AGE [15]	***3.5 Faults*** *Geological structures (i.e. faults) are shown on the conceptual model but their nature is not discussed anywhere in the report. They are noted at boundaries of the basin and between formations. The conceptual assumptions around these features should be discussed, as well as the approach to simulate them. Faults may act as barriers or as vertical and horizontal conduits, so it is important to identify this in the text and discuss how they are dealt with. Not representing them in the model will lead to a conservative response if they are barriers but may not be conservative if they provide heightened vertical connection. Maybe this is something that could have been tested in sensitivity analysis.*	Geological structures (faults) are discussed in **Sections 4.1.4 and 4.1.5**, and faulting and groundwater behaviour considered in **Section 5.6.8**. A review of geological logs WMP10D, WMP17D, STX1201C and STX052C was also undertaken by CQCPL's geologists. While a specific fault delineation program has not be undertaken, it is recommended that during the course of refined resource definition activities during operations be undertaken (east of open cut) as described in **Section 10.1.9**. A cross-section and concept description of the fault (and throw magnitude) is provided in **Figure 4-5[e]**. Drilling of WMP31 (**Attachment 7**) east of the fault confirms the presence of the stratigraphic change. With the installation of four vibrating wire at depths of 50 mbgl, 94 mbgl 103.5 mbgl and 171 mbgl, the monitoring location provides the opportunity to monitor whether the fault was to act as a barrier or conduit. As described in **Section 7.4,** the model mesh incorporates the structural interface between Styx Coal Measures and Bowen Basin (Back Creek Group, Boomer Formation and Carmila Formation) with input from CQCPL's geologists. During the preparation of this report it was recognised that whilst the IESC draft Explanatory Note for Fault Characterisation was still under development by the author Titus Murray (*Item 3.2 in IESC Meeting 67, 2-3 March 2020 Minutes, dated 20 March 2020*), it was a matter for careful consideration and therefore also reviewed as a component of the conceptualisation (**Sections 4.1.4, 5.6.8 and 6.3**) and uncertainty (sensitivity) analysis (**Section 8.11.3**).
103	AGE [16]	***3.6 Conceptual Water Balance*** *The conceptual model is missing a conceptual water balance, where the identified bulk water movement in, through and out of the aquifer is quantified at a level commensurate with the model objectives. A water balance from the conceptual model will help identify if there are missing components of the conceptualisation, and whether the assumptions are plausible. Some estimates (such as assumed rainfall percentage) are provided, however this is not taken to the next logical step and discussed as a volume across the adopted study area.*	A conceptual water balance is provided in **Section 6.3.7**. During the development of the numerical groundwater model (and as part of the peer review; **Table A2-5**) plausible checks for applied ET rates (i.e. 1.3 %) were also made to confirm modelled values were realistic.
104	AGE [17]	***3.7 General Comments*** *There is a lot of water quality / water chemistry data presented in the main body of text and it might be better to locate this to an appendix of its own, possibly only tabulating any critical exceedances of water quality objectives to go with the text, or even a summary of what was found. This would make the document more readable and would lead better into the culminating discussion of the conceptual model.*	Dataset summaries are presented in **Section 5.0.** As described in **Section 5.5**, the groundwater quality analysis has not been repeated in the report, however has been augmented with additional datasets collected during sampling by CQCPL in 2019 and relevantly discussed.

Table A2-3 (Continued)
Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
105	AGE [18]	***4.1 Model Confidence Level*** *For impact assessments the model should be aiming for a Class 2. This is especially the case with sensitive environmental receptors. The report indicates that the model meets all the Class 1 requirements and some of the Class 2 requirements. Components limiting the Class 2 assignment include the prediction period far exceeding the calibration period which is a difficult component to overcome without discovering long term historical observations to use in the calibration.*	The numerical groundwater model review of confidence level checklists are included in **Attachment 10** and have been augmented based on the IESC's Information Guidelines *Explanatory Note: Uncertainty Analysis – Guidance for Groundwater Modelling within a Risk Management Framework* (dated 17 December 2018) and discussed in **Section 8.12**.
106	AGE [19]	*The other component identified is the lack of stream gauging leading to baseflow estimates. Given the potential impact on groundwater / surface water interactions from the project and that the surface drainage connects the Project to some of its receptors, this is a significant limitation.*	Stream flow datasets have and continue to be collected at gauging stations installed at Tooloombah Creek and Deep Creek with corresponding dataloggers in alluvial groundwater bores (WMP04 and WMP05). As discussed in **Section 5.4.2**, since the installation of dataloggers in WMP04, WMP05 and WMP29A and the gauging stations on Deep Creek and Tooloombah Creek in September/October 2019 there was not a rainfall event of significance to record a response in the shallow groundwater levels for the calibration period. This is specifically recognised as a planned limitation (**Section 7.7.1**). Continued baseline data collection at the gauging stations and alluvial groundwater monitoring bores will allow future validation of the groundwater model.
107	AGE [20]	*Regarding data availability, it is not clear if the available observed water level behaviour is indicative of the average seasonal fluctuations. This is because of the declining CDFM calculated from data near the site over the period of available data. Deeper observations from the coal measures would not be expected to vary much, however the shallow groundwater in the weathered regolith and alluvium would be expected to vary with climate, and probably have a seasonal response that goes beyond what has been collected to date.*	As demonstrated by **Graph 3-2**, and included in the extended calibration datasets, flood (recharge) events resulting from the higher intensity rainfall (including tropical cyclones Tasha [during 2010-2011 flood event], Oswald [during January 2013] and Debbie [during March 2017]) is provided in **Sections 3.3 and 7.5.4**. As described in **Section 7.7.4**, the long term historical below average rainfall trends can be observed in the model outputs as well as more recently (2018-2019) (**Attachment 8**) with changes in groundwater levels corresponding with below average rainfall periods around the 1960s, 2000s and approaching 2020. As recommended in **Section 10.1.1**, additional groundwater level monitoring, particularly the monthly suite (select bores) WMP16-WMP30, should continue to augment baseline datasets.

Table A2-3 (Continued)
Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
108	AGE [21]	***4.2 Model Structure*** *A quick review of the model files indicates that each model layer contains the same number of active cells and therefore all model cells are active in each layer. There is no clear discussion around what happens to the cells that are in a layer that do not represent the HSU that the model layer represents (i.e. the model cells in layer 4 that are outside of the Styx Coal Measures). The model files indicate layer thickness is generally a nominal 5 m thick in these areas. While not critical, MODFLOW-USG does allow for model layers to truncate where the represented geology ends.*	The model layer approach (including active/inactive cells) is described in **Sections 7.4.1 and 7.5.2**.
109	AGE [22]	*The model extent is appropriate based on the predicted extent of impacts. The mesh design and discretisation provide sufficient resolution (40 m cell spacing) across the mine pits and even more resolution (20 m cell spacing) for where the two main surface drainages are closest to the project site.*	The refined USG mesh design and model domain geometry is described in **Section 7.4**.
110	AGE [23]	***4.3 Model Boundary Conditions*** *The surface processes in the tidal zone of Styx River are dynamic, however on the timeframes that the groundwater model operates it is entirely appropriate to represent this as a constant head.*	Agreed. Boundary conditions are described in **Section 7.5.1**.
111	AGE [24]	*However, no data is presented to support the assigning of 2 mAHD at the northern boundary of the model along the tidal areas, such as any corrections for density to develop and equivalent fresh water head. It also might not be as simple as adopting the average tidal height at the location. The adopted value is not tested in any way in the uncertainty analysis or sensitivity runs. The gradient towards the coast can influence how far impacts are likely to propagate and a variation of even half a metre at the coast could have an impact on either increasing or decreasing the extent of predicted impacts.*	As described in **Section 7.5.1**, based on a review of tidal influence and long-term sea level records (**Section 3.3**) the chosen elevation of the fixed head boundary applied was 3.5 mAHD. A sensitivity range of 2 mAHD (as previously modelled) to 4.5 mAHD has been considered in the uncertainty (sensitivity) analysis (**Section 8.11.3**). It is noted that the recorded long term mean sea levels are 3.42 mAHD and 2.47 mAHD at Hay Point and Rosslyn Bay respectively. Tide monitoring (at Ogmore Road Bridge) would continue to be recorded periodically to allow the range of predicted stage water levels in the Styx River to be validated and constant head boundary conditions (**Section 10.1.3**). Similarly, groundwater quality monitoring would continue to be undertaken at the WMP29 Series (A-E) Bores to inform any further freshwater / saline interface investigations, as and if required. Monitoring of elevated salinity at WMP26 (albeit above 7 mAHD) would also continue.

Table A2-3 (Continued)
Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
112	AGE [25]	***4.4 Representation of Dewatering*** *Section 10.5.6.8 of Document 1 suggested that dewatering through external (to the pit) bores was also being considered. How this may vary predicted drawdown from sump pumping would depend on the specifics of these bores such as location from the pit, number of bores, and spacing, however there is an opportunity for the drawdown to extend further with this dewatering approach.*	As described in **Section 8.3.1**, advanced dewatering, if required during the life of the CQC Project, would be temporary and, whilst external to the advancing open cut sumps, would be installed inside the proposed open cut footprint as sacrificial bores/pumps. Therefore, besides the drain cells applied to the advancing open cut, no other drain cells are modelled beyond the proposed open cut extents. Thus, whilst the timing for the effect of drawdown may change, the maximum predicted drawdown predictions would remain unchanged, and there would be no additional development footprint for the dewatering infrastructure.
113	AGE [26]	*The Styx Coal Measures are represented by three model layers in the model. Putting aside the comments regarding simulating the coal seams separate from the interburdens, the presented cross sections (Figures 3-52, 3-53, 3-55, 3-56) show mine pits that extend below the assumed basal coal seam. It is unlikely the pit shells will extend much beyond the basal coal seams in reality, though this needs clarifying. There appears to be a miss match between the pit shells and the basal coal seams, as it is unlikely the mining will progress beyond the lowest target coal seam.*	Mine pit drain depths to have been applied consistent with the separation and aggregation of model layers (including basal coal seams) and described in **Section 7.4**. The pit floor elevations are described in **Section 8.3.1**, with the deepest drains at -146 to -152 mAHD in Open Cut 2 (east/north-east), and -123 mAHD in Open Cut 1 (north-east).

Table A2-3 (Continued)
Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
114	AGE [27]	*With thoughts that this might have just been a presentation error in the cross section, the drain package was reviewed and it was identified that the drain boundary conditions are applied to layer 5 (underburden) and cells are dewatered to a level that places the base of the pit well within layer 5. Spot checks indicated this to be 10s of metres below the layer representing coal seams.* *It is assumed then the drain elevations are derived from pit elevations supplied through the mine plan, and not driven by the model structure. Ideally the model structure would be matched to the pit dimension so that when properties are changed in cells (such as backfill being applied), the entire cell where the change is occurring is desaturated, so that an increase in storage (as would be associated with backfill) does not 'create' more water in the system. If the model cell still has a level of saturation and the storage properties are increased, then the model 'creates' water. Furthermore, it is assumed that the supplied pit shells are based on the basal coal seam to be mined at the site. If these pit shell elevations are below the base of the layer designed to contain the coal seams, then it is likely the defined base of layer 4 (Styx Coal Measures and interburden) is not deep enough.* *Review of the model files also indicated that drain cell elevations in model layers that are completely mined out are assigned elevations that are approximately 10 cm above the base of the layer. It is not clear why this is done, as there should be no problem assigning the drain elevation to equal to cell bottom elevation. It is noted that this may be of no major consequence to the model predictions.*	Mine pit drain depths to have been applied consistent with the separation and aggregation of model layers (including basal coal seams) and described in **Section 7.4**. The pit floor elevations are described in **Section 8.3.1**, with the deepest drains at -146 to -152 mAHD in Open Cut 2 (east/north-east), and -123 mAHD in Open Cut 1 (north-east). As described in **Section 8.3.3**, the backfilling process is simulated by applying Time-varying Material (TVM) properties to reflect the changes in the host rock properties (pre-mining) to reflect the backfill spoil (broken, less consolidated rock), and was applied generally consistent with the backfill schedule provided.

Table A2-3 (Continued)
Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
115	AGE [28]	***4.5 Model Approach and Steady State*** *The reporting indicates that the model was calibrated to both steady state and transient conditions. It is not clear from the text in the calibration section whether the steady state calibration was undertaken with a steady state model or the long-term transient stress period that approaches steady state conditions (and that is part of the transient predictive run). If there is a disconnect and the calibration has been undertaken with a steady state model, then it is unclear why a transient pseudo steady state approach is required for the predictions.* *The report mentions issues getting the steady state model stable for convergence, so it is assumed that this would have been a concern for calibration where a range of parameters are being tested. Therefore, it is entirely possible the calibration was done with a transient model that represented the 'warm-up' steady state approximation. The method should be clarified in the reporting to remove any confusion.* *If the long-term approach has been adopted, and the calibration is using this then the initial conditions for that long transient stress period could influence parameters during a calibration process if it is significantly away from the true steady state water levels. The generation of the initial conditions (heads) also needs to be documented. The likely approach is that the observed water level data was contoured up and this would explain the significant water budget numbers in the first timestep of the long-term transient model.*	The model calibration approach is described in **Section 7.7** with results of steady state, pre-calibration and transient calibration, as well as vertical head gradient comparisons and extrapolated residual contour mapping in **Section 7.7.4**. The approach for cumulative assessment (incorporating historic mine workings) is described in **Sections 7.5.6 and 8.10**.

Table A2-3 (Continued)
Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
116	AGE [29]	***4.6 Backfilling and Final Voids*** *The simulation of the backfilled voids having the same properties as the in-situ Styx Coal Measures would have the effect of accelerating the recovery in the backfilled areas (due to storage values). This accelerated recovery would reduce the opportunity for continued propagating of the drawdown from already mined areas. Its noted that the backfilled spoil will be potentially compacted to some degree based on the mining method (i.e. trucks driving over spoil), however it is unlikely the spoil will get close to its pre-mining formation hydraulic conductivities and 25torativity.* *MODFLOW USG allows for the aquifer properties to change with time using the Time Variant Materials (TVM) package. This is available through the "Further Developments" version of MODFLOW-USG, which is also available through the Groundwater Vistas pre-processor as the 'beta' version.*	As described in **Section 8.3.3**, the backfilling process is simulated by applying Time-varying Material (TVM) properties to reflect the changes in the host rock properties (pre-mining) to reflect the backfill spoil (broken, less consolidated rock), and was applied generally consistent with the backfill schedule provided.
117	AGE [30]	*It is noted that later in the uncertainty analysis more appropriate backfill properties are explored through a sensitivity scenario, though it is not clear if this was applied progressively through the time variant material properties package, or if it was specified prior to mining, or was only assigned during the recovery period.*	As described in **Section 8.3.3**, the backfilling process is simulated by applying Time-varying Material (TVM) properties to reflect the changes in the host rock properties (pre-mining) to reflect the backfill spoil (broken, less consolidated rock), and was applied generally consistent with the backfill schedule provided.

Table A2-3 (Continued)
Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
118	AGE [31]	*With the voids fully backfilled the likely result is that the mined area becomes a flow through system. This seems to be the case here with the predicted recovered conditions almost identical to the pre-mining conditions and predicted groundwater levels showing gradient through the backfilled voids. Depending on the cover / final landform design over the backfilled material, there may be opportunity for heightened recharge to the backfilled voids to occur, which may result in mounding of the groundwater level. It is the reviewers understanding that this has not been simulated. If that is the case, then the option should be explored for its impact on modifying the flow directions and mobilising any potential contaminants within the backfilled material.*	In the long-term, all voids would be backfilled and groundwater levels would substantially recover over many decades as detailed in **Section 8.9**. Some localised mounding is predicted to occur where the final landform surfaces are elevated above the existing surface, and the resulting net gain effects evident in the predicted changes in baseflows and/or lesser leakage in Tooloombah Creek and Deep Creek after approximately 150 years (**Graph 8-3**).
119	AGE [32]	***4.7 Calibrated Model*** *The reporting indicates the model calibration has taken place through both a steady state and a transient model. Section 3.4.3.4 describes the use of a long transient stress period to approximate the steady state, however Section 3.5.1 of the report dealing specifically with the calibration describes that the model "has been calibrated in steady state". Because of the closeness of the water budget from the long-term transient simulation in the supplied model files and the reported water balance in Table 3-7, is has been assumed that the long-term transient model is providing the steady state results for the calibration. This approach is acceptable, but there could be more transparency in reporting this. Additionally, it is important to ensure that steady state conditions have been achieved, for both water budgets and water levels across the model domain (see Section 5.1 below).*	The calibration approach is articulated in **Section 7.7.1**.

Table A2-3 (Continued)
Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
120	AGE [33]	*The calibrated Scaled RMS (SRMS) statistic of 1.9% is helped by one observation at 300mAHD. If this is removed, the observation range would become approximately 150 m, and the SRMS would double, but still be within acceptable limits without the large range created by the much higher (and potentially disconnected) observed water level. Changing the achieved SRMS could have ramifications to the acceptance of model runs in the uncertainty analysis if the SRMS has influenced the threshold applied to retain or dismiss models.*	The scaled root mean square (SRMS) error for the transient calibration is 2.01%, where < 10% is the often-used criteria for acceptable model calibration (Barnett et al., 2012) and is discussed further in **Section 7.9** and presented **Attachment 10 (Table A10-4)**.
121	AGE [34]	*The calibration level of fit is also shown in the scatter diagram in Figure 3-11. The reference to the colour range of the points is not discussed, but it is assumed this is based on the level of error. It would be useful to see this coloured based on whether the data point is transient or steady state or based on the geology the observation point represents.*	The groundwater level steady state and transient calibration plots (observed versus computed groundwater levels) are presented in **Graphs 7-1 and 7-2**. Map of average transient residuals to highlight the calibration performance across the model domain is presented in **Figure 7-6 [a]**. A zoomed-in inset for comparison is presented in **Figure 7-6[b]**.
122	AGE [35]	*The adopted calibrated aquifer parameters are shown in Table 3-4, and the calibrated recharge is shown in Table 3-5. Calibrations involving both recharge and hydraulic conductivity are notorious for non-uniqueness because the two parameter types are highly correlated. An increase in recharge can be matched by an increase in hydraulic conductivity to attain the same level of calibration.* *The calibration is limited by only calibrating to water level observations. Non-uniqueness can be reduced by calibrating to different types of observations (i.e. base flow estimates), however it is understood that flow data is not available.*	A combination of parameter identifiability, sensitivity and qualitative analyses have been used to identify bounds (or constraints) by available observations and then investigate if and/or how such parameters affect the model predictions. This recognises the challenge of non-uniqueness, and the possibility that multiple combinations of parameters may be equally good at fitting historical measurements, but has been used in support of the combination of parameters applied. Refer to **Sections 7.7.1 and 8.12** regarding planned limitations, recognising that the stream flow gauges were installed in September-October 2019 and no flow events were recorded to the end of 2019 post-installation. Similarly, VWP installations require several months to equilibrate, thus a validation opportunity only. Therefore, the objective is to present robust uncertainty analysis and allowance for future validation.
123	AGE [36]	*From Figure 3-10 it appears that only 3 observation bores (RN91728, RN91726, and BH30) were targeting the coal measures – the most critical model layer for the predictions being made, with another two bores (WMP16 and WMP29) added during the verification. Further to this, all these bores are located away from the location of the proposed dewatering.*	Note WMP22B and WMP30B are screened in the coal seams.

Table A2-3 (Continued)
Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
124	AGE [37]	*The discussion on the calibration results could be improved by some comparisons to the conceptual model. For example, areas identified in the conceptual model for groundwater / surface water interaction can be checked in the model, to see if the same interaction is simulated.*	Additional discussion is included in **Section 7.7**.
125	AGE [38]	***4.8 Predictions*** *Based on experience with similar models the pre-mining water budget appears plausible, in both the magnitude of the input and output for the extent of the model, and for the relative distribution of the components of the water balance. Ideally this would be compared to the conceptual water balance to confirm the assumptions.*	Comparisons with the conceptual water balance are provided in **Sections 6.3.7, 7.7.5 and 8.8**.
126	AGE [39]	*The predictions of drawdown appear to be plausible given the aspects of the model already discussed. The drawdowns are derived from the differencing between a prediction model (mine represented) and a null model (no mine represented), which the Australian groundwater modelling guidelines advise is a preferred method that can reduce uncertainty in the drawdown estimates.*	Model variants (including null, cumulative and project alone) are described in **Table 7-9**.
127	AGE [40]	*Figure 3-38 presents the predicted inflow to the mine and provides an indication of the take from different geologies. This seems to be based on the drain cells only, as the take from the alluvium is very small, but could be due to the level of saturation. Also, based on what has been noted about the drain package, should there also be a component for the underburden in the graph? The take from the different geologies will need to be presented in a clearer manner, perhaps tabulating the peak annual take, and would require some zone budgeting on the alluvium (which may have been achieved already through looking at flux changes for GDEs) to determine the take if licencing is required.*	Direct groundwater take/inflows for the purposes of accounting if licensing is required is described in **Section 8.4**.

Table A2-3 (Continued)
Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
128	AGE [41]	*In the supplied documents the impact to some existing users is shown through a series of hydrographs (Figures 3-45 to 3-47). While the hydrographs provide some great insight to predicted impact with time, it should be complimented by tabulating all the identified existing user bores and listing the maximum predicted drawdown at each location – possibly as an appendix of Document 2.*	Tabulation of predicted drawdown impacts on private landholder bores is provided in **Section 8.7.1** (**Table 8-4**).
129	AGE [42]	***4.9 Uncertainty Analysis*** *The IESC have recently released a guideline to ensure robust estimates of uncertainty around model predictions they review. A calibrated language has been devised that provides consistency in the presentation. Many of the aspects of the uncertainty guidelines are addressed with the approach reported in Document 2. The process of exploring the null space aligns with the guideline, as does the exploration of extremes through some breakpoint scenarios.*	Specific reference to the IESC's Information Guidelines Explanatory Note: Uncertainty Analysis – Guidance for Groundwater Modelling within a Risk Management Framework (dated 17 December 2018) is provided in **Section 1.0**. Uncertainty Analysis is presented in **Sections 8.11 and 8.12** and outputs in **Attachment 11**.
130	AGE [43]	*Parameter identifiability has not been reported for all the parameters. This can be presented as a bar chart for each parameter showing the parameter identifiability directly from PEST.*	Parameter identifiability is reported in **Section 8.11.1**.
131	AGE [44]	*The uncertainty analysis using the Null Space Monte Carlo (NSMC) method is an appropriate approach to quantifying uncertainty, and in particular, using the standard PEST methodology with two optimisations per realisation. The report discusses 190 simulations becoming 129, and then 106, however the criteria for the rejected 84 simulations is not disclosed in the reporting, apart from being "inconsistent with the hydrogeological conceptualisation".*	Latin Hypercube Sampling (LHS) is a statistical method which has been used (*in lieu* of the Monte Carlo Sampling which was undertaken for the previous numerical groundwater model [**Section 7.1.1**]) to generate a near-random sample of parameter values from the above multi-dimensional distribution. Other benefits of using LHS (e.g. simplicity and speed) are outlined in **Attachment 11**. As described in **Section 8.11.2**, a total of 1,000 model runs were completed with a calibration cut-off of 3% SRMS (i.e. 50% greater than the original transient calibration model).
132	AGE [45]	*The reason to undertake the additional 'recharge / Kh' simulations beyond what would have been captured in the NSMC process is not clear, unless the conductivities tested were outside of the ranges set up for the NSMC.*	As described in **Section 8.11.2**, ranges and distributions applied to hydraulic properties in the improved numerical groundwater model as part of the quantitative uncertainty analysis (**Attachment 11**) included lognormal distribution with 0.5 standard deviation for $K_{Horizontal}$/Infiltration% ratio.

Table A2-3 (Continued)
Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
133	AGE [46]	*It is not clear if the box and whisker plots (Figures 3-58 and 3-59) represent of the posterior distributions. It is also not clear if these represent the 106 NSMC runs, or the 23 Monte Carlo runs which tested correlation between recharge and horizontal hydraulic conductivity. It is possible that the whiskers represent min and max, the box extents represent the p25, p50 (line in the box), and p75, and the 'x' represented the baseline calibrated value, but that is not clear for the reader.*	Plots have been superseded. Prior and posterior distributions are specifically considered in **Attachment 11**.
134	AGE [47]	*The presentation of the 'worst case' parameter set in Table 3-12 shows that the parameter set looks very similar to the base case in most aspects. Has the true worst case scenario really been explored? Potentially the posterior range from the uncertainty analysis is very narrow. This usually happens when layer wide parameters are used in data rich models. Identifiability becomes artificially high, meaning that by changing a single parameter slightly, it impacts the calibration statistics and leaves the null-space.*	Prior and posterior distributions are specifically considered in **Attachment 11**.
135	AGE [48]	*The breakpoint parameter testing is commendable, particularly the use of key observation points as triggers, with the idea being that the parameters that do cause some minor impact would be beyond what is considered reasonable for that geology. The changes are listed in Table 3-14 and do show some significant changes, but only limited to hydraulic conductivity. There are perhaps other model parameters, such as the elevation of the tidal constant head boundary condition, that could be varied based on uncertainty about the assumptions made that may also cause a variation of predictions.*	As described in **Section 7.5.1**, based on a review of tidal influence and long-term sea level records (**Section 3.3**) the chosen elevation of the fixed head boundary applied was 3.5 mAHD. A sensitivity range of 2 mAHD (as previously modelled) to 4.5 mAHD has been considered in the uncertainty analysis (**Attachment 11**). It is noted that the recorded long term mean sea levels are 3.42 mAHD and 2.47 mAHD at Hay Point and Rosslyn Bay respectively. Tide monitoring (at Ogmore Road Bridge) would continue to be recorded periodically to validate the range of predicted stage water levels in the Styx River undertaken as a component of the uncertainty analysis (i.e. range of constant head boundary conditions considered) (**Section 10.1.3**). Similarly, groundwater quality monitoring would continue to be undertaken at the WMP29 Series (A-E) Bores to inform any further freshwater / saline interface investigations, as and if required. Monitoring of elevated salinity at WMP26 (albeit above 7 mAHD) would also continue.

Table A2-3 (Continued)
Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
136	AGE [49]	*In Section 3.7.2.3 the results are presented on a model by model basis, rather than looking at the range of predictions and then reporting likelihood of key outputs. The uncertainty analysis is about building a database of potential model outputs, such that at any model cell you can report on the likelihood of occurrence of a particular prediction above (or below) a certain threshold. The new guidelines provide the methods the generate and produce these outputs, as well as defining the likelihood ranges expected. This then combines all the model runs into a single output, and outputs like the maximum drawdown predicted across the model domain or mine inflow will come from a number of model runs, which with different parameters will impact in different areas or different times.*	Robust uncertainty analysis is described in **Sections 8.11 and 8.12**. Outputs from the Uncertainty Analysis are presented in **Attachment 11**.
137	AGE [50]	***5.1 Stress Period Length*** *The one and only difference between what has been reported and what was in the model files was the reported stress period length of the first stress period. The reporting indicates the stress period is 10,000 years, however the model file has stress period 1 at 42,735 days (117 years). I would suggest that maybe a previous version of the model used the 10,000-year stress period length, however further model development has identified that this is not required and that a shorter model run would be sufficient to approach an approximate steady state.*	Model stress period lengths are described in **Sections 7.6.1 and 8.2.2**.

Table A2-3 (Continued)
Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
138	AGE [51]	*The reviewer was able to successfully run a steady state stress period at the start of the simulation and was able to achieve convergence in under 100 iterations. The only changes made to the model files were to enable the first stress period to be steady state and the stress period length to be 1 day. This was using the current official release of MODFLOW-USG (Version 1.4.00) and with a version of the 'Further Developments' beta version of MODFLOW-USG. It was found that the reported daily water budget for the final timestep of the first transient stress period (approximating steady state conditions) was close, but does not completely match the water budget for the steady state model with the long transient stress period overpredicting the evapotranspiration budget by around 200 m3/day and over predicting baseflow to surface drainage a further 12 m3/day.*	Noted.
139	AGE [52]	*A check of the steady state water levels against the transient generated starting water levels shows some discrepancy, with an average difference of around 6 cm with the transient generated water levels over predicting up to 23 m in some model cells and under predicting to almost 5 m in another area of the model. Generally, the larger mismatch is confined to more elevated areas though differences of up to half a metre are noted close to the project site (see Figure 1 below), and it is difficult to know how this has influenced the calibration or uncertainty analysis.*	The model generated groundwater levels are presented on the hydrographs in **Attachment 8** with the steady state target for comparison.
140	AGE [53]	***5.2 Model Parameters*** *The specific yield assigned to layers 3 to 6 was set to the adopted alluvium value of 1%, not the reported 0.5%.*	The modelled hydraulic properties are described in **Section 7.7.3**.

Table A2-3 (Continued)

Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
141	AGE [54]	*The alluvium hydraulic conductivity is assigned in some cells down to layer 5. As a nominal thickness of 5 m is assigned to various layers, this could mean an alluvial thickness of at least 25 m, or more if there are noted (not nominal) thicknesses in layers 1 and 2 (which seem to be a split of the interpolated thickness). This seem to have also crept into the Styx basin area where some cells which seem internal to the basin are assigned alluvium properties. It is possible that the basin has eroded in parts, but this should be checked for reality.*	The coal measure stratigraphy is described in **Section 4.2.1**. Separation and aggregation of model layers has been applied in the numerical model as described in **Section 7.4.1**. Hydraulic parameters have been considered and are discussed in **Sections 5.6.4 to 5.6.6**. Modelled hydraulic properties are described in **Section 7.7.3**, and includes vertical anisotropy.
142	AGE [55]	*The variability of the hydraulic conductivity in layers 3, 4, and 5 within the Styx basin extents was a surprise. The report indicates (i.e. Table 3-2) that these layers are applied with a single value for each layer. Instead it appears that the model layers are more horizontal than the dip in the vertical HSU divisions and therefore cut through the dipping strata to some extent, with all three HSU divisions of the Styx Coal Measures appearing to different degrees within all three layers that represent them.*	The model structure/layers are described in **Section 7.4**.
143	AGE [56]	*It is possible the supplied model files are not representative the calibrated base case, however there was nothing in the file names to indicate that the model files are from any uncertainty / sensitivity testing, and the specific yield values and nominally thick alluvium uncovered in the model files are not likely to form a logical test model. If these are the correct model files then the numerical model will need to be corrected to match the conceptual model.*	Noted.
144	AGE [57]	*The structure changes suggested around representing the coal seams as separate layers and making use of MODFLOW-USG's ability to truncate model layers will change the representation of the Styx Coal Measures.*	Separation and aggregation of model layers has been applied in the numerical model as described in **Section 7.4.1**.

Table A2-3 (Continued)
Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
145	AGE [58]	***5.3 Fixed Head Cells*** *The reviewer has extracted the fixed head cells from the time variant constant head package (CHD) and identified that the distribution of cells does not quite match those presented in Figure 3-6. This is because the defined water level is below the defined base of the model cell. This can be easily rectified by lowering the base of the cell. Figure 2 below shows which CHD cells are active and shows some gaps. This won't significantly change the calibration or predictions; however, it is worth noting so it can be addressed.*	Noted and discussed in **Section 7.5.1**.
146	AGE [59]	*The design of boundary conditions near the fixed head boundaries is appropriate as there is no evidence of evapotranspiration or drain boundary conditions interacting with constant head cells causing a short-circuiting inflow to occur.*	Noted.
147	AGE [60]	***6.1 Document 1 – Section 10.5 of the Supplementary EIS [Editorial Specific Comments]***	Editorial comments made redundant. Refer to updated SEIS V3 Chapters prepared by Orange Environmental (2020).
148	AGE [61]	*This figure shows the alluvium hydrographs and it appears there could have been a mix up in the depth to water levels recorded for BH01X and BH16 in September 2017. Unless there is a specific event or surface process that can explain the rise in one and the fall in the other, then is it likely a recording error for these two bores. The rogue measurements fit exactly into the other's general decline.* *Some bores (i.e. WMP05 and WMP08) seem to show a recovery after drilling. These initial data points are not likely to be indicative of the recharge at the time and could be removed from the hydrographs. This would give a lower estimate of 'seasonal variation' on the preceding page (2nd dot point).*	Additional datasets for BH01X, BH16, WMP05 and WMP08 are presented on the hydrographs in **Attachment 8** and discussed in **Section 5.0**. The BH01X and BH16 datasets were adjusted accordingly. Datasets where recovery after drilling is considered has been removed from statistical datasets.
149	AGE [62]	*What is the cause of the small decline in bores WMP10, WMP11D and WMP13 around August 2018? Is it due to hydraulic testing?*	Additional datasets for WMP10, WMP11D and WMP13 are presented on the hydrographs and discussed in **Section 5.0**.

Table A2-3 (Continued)
Summary of AGE Consultants Peer Review of CDM Smith Styx Groundwater Model Comments [5 February 2019]

ID	REVIEW [REF]	PEER REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
150	AGE [63]	***6.2 Document 2 – Section 3 of Appendix A6 of the Supplementary EIS [Editorial Specific Comments]***	Editorial comments made redundant. Refer to updated report.
151	AGE [64]	*Text mentions that drains are removed after 1 year of mining, but it is mentioned in other parts of the report that the pit operating window is 3 years. Is there inconsistency here?*	Drains have been applied in the numerical groundwater model as described in **Section 8.3.1**.
152	AGE [65]	***7. Conclusion*** *The review has identified several aspects of model development that need to be addressed. With this in mind, the modelling guideline checklist has not been completed.*	A peer review has been completed by AGE Consultants (2020), including consideration of AGMG checklists (**Attachment 10**).
153	AGE [66]	*The major issues stem from the representation of the coal measures as a single entity, instead of individual coal seams. The stratigraphy indicates that the grouping of coal seams such that the total thickness of coal seams can be represented with coal seam properties is possible, and it is indicated that the local geological model has this information readily available.*	The 2018 geological model stratigraphic picks have been assigned consistent with groundwater conceptualisation. Geological cross-sections based on 2018 geological model are presented in **Section 4.2.2**. Separation and aggregation of model layers has been applied in the numerical model as described in **Section 7.4.1**.
154	AGE [67]	*Review of the model files indicated that differences do exist between what is in the model and what is reported. It is not clear if this is an issue with the reporting, or an incorrect parameter assignment in the model files. Because the reporting is consistent throughout, it is feared that it is the latter. The parameter is unlikely to influence the drawdown extent, but it is expected to modify the predicted inflow.*	Parameter assignment in the numerical groundwater model has been described in **Section 7.7.3** and AGE Consultants has reviewed the model files during the course of the peer review.
155	AGE [68]	*It is assumed that the occurrence of overly thick alluvial zones through the transfer of aquifer parameters from above in areas where a nominal thickness exists has not been deliberate. A change in the structure for the Styx coal measures and utilising MODFLOW-USG's ability to truncate layers will remove this if required.*	Separation and aggregation of model layers has been applied in the numerical model as described in **Section 7.4.1**.

Table A2-4

Summary of AGE Consultants Stage 1 Independent Peer Review Findings [20 December 2019]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
156	AGE [69]	*AGE also previously undertook a peer review of the CDM Smith model and associated reporting thought to have been used for the AEIS. Key findings of this review which are potentially of relevance to the revised model being developed by HA are as follows:*	Specific reference to each matter is provided in **Table A2-3**, with further consideration below for each of the key findings.
157	AGE [70]	• *Only three layers have been used to represent the coal measures as a whole and there is no dedicated coal seam layer, each layer therefore comprises a mixture of coal and interburden;* • *The use of dedicated coal layers which include reducing hydraulic conductivity with depth is recommended;*	As described in **Section 7.4**, the updated model layers have been separated and aggregated. The hydraulic parameters applied are based on a review of aquifer testing, literature and prior modelling in **Section 5.6**. Modelled hydraulic properties are described in **Section 7.7.3** and includes vertical anisotropy. Depth dependence for the coal seams (with reducing hydraulic conductivity [Kx]) is applied and approach presented in **Section 5.6.5**.
158	AGE [71]	• *No site specific test data appear to be available on the hydraulic properties of the coal seams;*	Site-specific packer testing was completed by AMEC (2019) (**Attachment 7**) which included coal seam intervals and is presented in **Graphs 5-2 and 5-3**. As described in **Section 5.6.5**, site-specific aquifer testing was also conducted at the groundwater monitoring bore (WMP22B) inferred to be targeting the coal seams at the CQC Project and six aquifer test solutions were determined.
159	AGE [72]	• *An unrealistically high vertical anisotropy of 1 has been assumed for the coal measures layers especially given that as mentioned above these layers comprise a mixture coal and interburden units;*	As described in **Section 7.4**, the updated model layers have been separated and aggregated. The hydraulic parameters applied are based on a review of aquifer testing, literature and prior modelling in **Section 5.6**. Modelled hydraulic properties are described in **Section 7.7.3** and includes vertical anisotropy.
160	AGE [73]	• *The location of the freshwater / saline interface is not mapped nor is there any discussion in the modelling report as to how this interface has been represented in the model;*	The location of the freshwater / saline interface, utilising the Ghyben-Herzberg relationship, is discussed in **Section 6.3.2**. As discussed in **Section 6.3.2**, WMP13 located several kilometres downstream of the CQC Project has recorded salinities indicative of seawater. As described in **Section 7.5.1**, based on a review of tidal influence and long-term sea level records (**Section 3.3**) the chosen elevation of the fixed head boundary applied was 3.5 mAHD. A sensitivity range of 2 mAHD (as previously modelled) to 4.5 mAHD has been considered in the uncertainty analysis (**Attachment 11**). It is noted that the recorded long term mean sea levels are 3.42 mAHD and 2.47 mAHD at Hay Point and Rosslyn Bay respectively. Tide monitoring (at Ogmore Road Bridge) would continue to be recorded periodically to validate the range of predicted stage water levels in the Styx River undertaken as a component of the uncertainty analysis (i.e. range of constant head boundary conditions considered) (**Section 10.1.3**). Similarly, groundwater quality monitoring would continue to be undertaken at the WMP29 Series (A-E) Bores to inform any further freshwater / saline interface investigations, as and if required. Monitoring of elevated salinity at WMP26 (albeit above 7 mAHD) would also continue.

Table A2-4 (Continued)
Summary of AGE Consultants Stage 1 Independent Peer Review Findings [20 December 2019]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
161	AGE [74]	• *Faults are shown in the conceptual model report but their nature is not discussed and their presence is ignored in the groundwater flow model;*	The structural setting including regional and local faults are described in **Sections 4.1.4 and 4.1.5**. The improved numerical model mesh has incorporated the structural interface between Styx Coal Measures and Bowen Basin (Back Creek Group and Carmila Formation), generally consistent with 1:100k geology mapping and with input from CQCPL's geologists. Lateral connection groups have been used to create horizontal flow connections across the mapped faults. Sensitivity and uncertainty analyses explore alternative hydraulic properties along the faults; these are discussed in **Section 8.11.3**. As described and presented in **Section 5.1.3** and **Attachment 4 (Table A4-3)**, CQCPL has installed a VWP north-east and east of the fault to validate the stratigraphy (Back Greek Group) and pressures at depth to below the base of the CQC Project open cut. *[It is noted that the IESC draft Explanatory Note for Fault Characterisation was potentially under development and had not been released for public consultation at the time of reporting]*
162	AGE [75]	• *No data is presented to support the use of a 2.0 mAHD constant head boundary associated with the tidal Styx River to the north of the proposed mining area;*	Long term mean sea level records are published by the Queensland Government in the Queensland Tide Tables Standard Port Tide Time 2019 (Maritime Safety Queensland, 2019) at locations along the Queensland eastern coastline to the north and south of the Broad Sound and summarised in **Section 3.3**. Corresponding local tide measurements at Ogmore Road Bridge on the Styx River are presented in **Section 3.3.2**. At a finer scale, hourly datalogging has also occurred at WMP29A to investigate the influence of tides on groundwater levels. Based on a review of tidal influence and long-term sea level records (**Section 3.3**) the chosen elevation of the fixed head boundary applied was 3.5 mAHD. A sensitivity range of 2 mAHD (as previously modelled) to 4.5 mAHD has been considered in the uncertainty analysis (**Attachment 11**). Tide monitoring (at Ogmore Road Bridge) would continue to be recorded periodically to validate the range of predicted stage water levels in the Styx River undertaken as a component of the uncertainty analysis (i.e. range of constant head boundary conditions considered) (**Section 10.1.3**).
163	AGE [76]	• *Model drain cells used to represent the open cut mining operations appear to extend below the base of the coal seams and interburden layer into the underburden layer which is described as being non-coal bearing;*	As the updated model layers have been separated and aggregated, the drain cells are applied to the base of relevant coal seam layer(s). The model drain cells in the updated model have been applied consistent with the annual mine progression in **Section 8.3.1**.
164	AGE [77]	• *It is considered unlikely that the hydraulic conductivity and storage properties of the material used to backfill the pits prior to closure would be the same as the in-situ Styx Coal Measures;*	The in-pit backfilling of waste rock, including timing, hydraulic properties and enhanced recharge used in the updated numerical groundwater model are included in **Section 8.3.3**. Time Varying Material (TVM) properties are being applied accordingly to correct the host properties.

Table A2-4 (Continued)
Summary of AGE Consultants Stage 1 Independent Peer Review Findings [20 December 2019]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
165	AGE [78]	• *Calibration has been undertaken through reference to water level observations only thereby increasing the potential for non-uniqueness. Calibration to flow estimates (e.g. estimated baseflow to local watercourses) was recommended, although it was noted that this was a data limitation.*	Calibration has been undertaken through water level observations. As discussed in **Section 5.4.2**, since the installation of dataloggers in WMP04, WMP05 and WMP29A and the gauging stations on Deep Creek and Tooloombah Creek in September/October 2019 there was yet to be a rainfall event of significance to record a response in the shallow groundwater levels for the purposes of calibration. Continued baseline data collection at the gauging stations and alluvial groundwater monitoring bores will allow future validation of the groundwater model.
166	AGE [79]	*Calibration data available at the time appeared to be limited to three monitoring points with time series data in the coal measures and only a single monitoring point in the basement.*	The groundwater monitoring points in the Styx Coal Measures (underburden) and Permian Measures (e.g. Back Creek Group) are described in **Sections 5.1.2 (Table 5-3) and 5.1.3 (Table 5-4)**. The extended calibration datasets are presented in **Section 7.7.4**. The steady state targets per model layer are presented in **Table 7-11**.
167	AGE [80]	*It is noted that a north-eastward extension to the previous modelling domain is proposed to include a larger portion of Broad Sound, a tidal monitoring point and the Wellington Creek catchment. Consideration should be given to whether the model domain needs to be this large given that impacts are likely to be largely contained within the Styx Basin and given the comments below relating to surface water boundary conditions (Section 3.6). Whilst there are arguments for including the whole surface water catchments of the Deep and Tooloombah Creek within the model domain and extending the model to the north to include more of the tidal Styx River, the proposed eastward extension to the coast appears to be excessive. Careful consideration should be given to the overall size of the model if such a large area is to be modelled.*	The north-eastern extension of the groundwater model was not extended as far as Rosewood Island during the actual model build, generally consistent with AGE Consultants commentary. The northern extents were cropped to be generally consistent with the mainland coastline. As described in **Section 7.5.1**, inclusion of the Styx River surface water catchment does however allow for the application of no flow boundary conditions in all layers at the topographic ridges (i.e. elevation of the water table is topographically controlled). Relevantly, the landholder database searches (**Table 5-7**) identified more than 10 additional records in the north-east (Wellington Creek and Tributary to Styx River Mouth) which provided additional SWL level and water quality datasets for model calibration. The north-east extension also allowed for consistent and relative comparisons of reporting catchments to the Broad Sound (at the Styx River mouth) (**Table 3-3**) (i.e. integrating surface water and groundwater assessment discussion). It is noted that the Broad Sound Fish Habitat Area (FHA-047) boundary is defined at the mouth of the Styx River by the cadastral boundary (at a point 20 m from and parallel to) the North Coast Line railway crossing of the Styx River (immediately downstream of the Granite Creek/Montrose Creek confluence with the Styx River), and therefore for the purposes of this groundwater assessment has been consistently defined and assessed accordingly. The updated model size and cell count are considered reasonable and is discussed in **Sections 7.1.2 and 7.4**.
168	AGE [81]	*Separate layers for coal and interburden are proposed with model parameters to be supported by additional test work. Further partitioning of Quaternary deposits is also proposed with the overall number of layers increasing from 6 to 13 layers. Without further information on the conceptual model it is not possible to comment on the suitability of the proposed layers, although obviously the increase in the number of layers and separation of the coal and interburden are positive developments.*	As described in **Section 7.4**, the updated model layers have been separated and aggregated. The hydraulic parameters applied are based on a review of aquifer testing, literature and prior modelling in **Section 5.6**. Modelled hydraulic properties are described in **Section 7.7.3** and includes vertical anisotropy. The Conceptual Groundwater Model is described in **Section 6.3**. See **Tables A2-5 and A2-6** for subsequent comments provided for the Stage 2 and Stage 3 peer review.

Table A2-4 (Continued)
Summary of AGE Consultants Stage 1 Independent Peer Review Findings [20 December 2019]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
169	AGE [82]	*A target of less than 1 million active cells for the new model is mentioned in Table 7-1 which also suggests that a variable mesh will be developed (presumably using Algomesh). Node spacings should be sufficiently small to allow accurate representation of the location of local surface water courses, proposed open cut pit walls, mapped regional faults, and key areas between these features where detail in predicted water level changes are required.*	The active cell count for the improved model is 489,611 cells. AlgoMesh has been used and node spacings applied as described in **Sections 7.2.3 and 7.4.3** (**Table 7-4**) for the open cut, stream reaches, faults and other relevant features.
170	AGE [83]	*It is understood that the major regional faults are to be incorporated into the model structure. Where displacements are significant compared to the thickness of the modelled strata, then MODFLOW USG non-neighbour connections should be considered. Initial parameterisation and calibration of fault parameters should be justified in the associated reporting. Conceptual models presented in the AEIS (CDM Smith, November 2018) suggest that the Styx Basin may be fault bounded in places so faults may play a key role in lateral impact propagation.*	The structural setting including regional and local faults are described in **Sections 4.1.4 and 4.1.5**. The improved numerical model mesh has incorporated the structural interface between Styx Coal Measures and Bowen Basin (Back Creek Group and Carmila Formation), generally consistent with 1:100k geology mapping and with input from CQCPL's geologists. Lateral connection groups have been used to create horizontal flow connections across the mapped faults. Sensitivity and uncertainty analyses explore alternative hydraulic properties along the faults; these are discussed in **Section 8.11.3**. As described and presented in **Section 5.1.3** and **Attachment 4**, CQCPL has installed a VWP north-east and east of the fault to validate the stratigraphy (Back Greek Group) and pressures at depth to below the base of the CQC Project open cut.
171	AGE [84]	*No flow boundary conditions along topographic ridges of the Styx River catchment and constant head boundary conditions for the tidal part of the Styx River are proposed. The tidal level is to be set through reference to data for nearby tidal gauges. Where possible reference should also be made to data for coastal groundwater monitoring locations to confirm the use of a time constant level. Given that the available data related to tide gauges is some distance away in oceanic rather than estuarine environments, then it would also be appropriate to both calibrate the modelled elevation and assess the uncertainty associated with the parameter. Levels in the estuary will also be influenced by surface water flows.*	Long term mean sea level records are published by the Queensland Government in the Queensland Tide Tables Standard Port Tide Time 2019 (Maritime Safety Queensland, 2019) at locations along the Queensland eastern coastline to the north and south of the Broad Sound and summarised in **Section 3.3**. Corresponding local tide measurements at Ogmore Road Bridge on the Styx River are presented in **Section 3.3.2**. At a finer scale, hourly datalogging has also occurred at WMP29A (a groundwater monitoring bore near the coast) to investigate the influence of tides on groundwater levels. Based on a review of tidal influence and long-term sea level records (**Section 3.3**) the chosen elevation of the fixed head boundary applied was 3.5 mAHD. A sensitivity range of 2 mAHD (as previously modelled) to 4.5 mAHD has been considered in the uncertainty (sensitivity) analysis (**Section 8.11.3**). Tide monitoring (at Ogmore Road Bridge) would continue to be recorded periodically to allow the range of predicted stage water levels in the Styx River to be validated and constant head boundary conditions (**Section 10.1.3**).

Table A2-4 (Continued)
Summary of AGE Consultants Stage 1 Independent Peer Review Findings [20 December 2019]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
172	AGE [85]	*Whilst additional drain boundary conditions are proposed for surface drainages, further justification is likely to be required on the continued use of this relatively simple boundary condition which only simulates flow from groundwater to surface water. Give the apparent importance of these water courses in supporting local GDEs and flow into the Great Barrier Reef (GBR) then consideration should be given to using a more complex boundary condition (e.g. MODFLOW streams) which can simulate both flow to and from surface water systems. We note that conceptual diagrams presented in CDM Smith AEIS groundwater report (CDM Smith, November 2018) refer to the Deep Creek and Tooloombah Creek as losing under certain conditions. If this is the current conceptual model then it may be difficult to justify the continued use of the drain package which can only simulate gaining conditions, especially since losing conditions are almost certain to occur during and post development, given the proximity of the proposed open cut to these water courses.* *It is understood that some flow data is now available for gauging stations installed on the Deep Creek and Tooloombah Creek. Hopefully this data will be sufficient to both justify the choice of boundary conditions and generate data for calibration (e.g. gauged actual flow gains and losses).* *Whilst it is recognised that flow in these water courses is likely to be highly ephemeral, the Tooloombah Creek in particular drains a relatively large catchment and a substantial amount of flow (both groundwater and surface water) will pass down the creek during wet periods. Post mine development there is potential for a proportion of this flow to be lost into the mine workings with consequent impacts on sensitive receptors downstream.*	The justification for the use of River (with Stage = 0) boundary conditions is presented in **Section 7.5.3**. Use of river cells (instead of drain cells) has the benefit of simulating losing conditions, particularly if such conditions were to be enhanced during and/or post-mining. The reasons for not applying MODFLOW stream cells (i.e. unnecessary over-parameterisation) is also detailed. GDEs and corresponding depth to groundwater measurements are described and presented in **Section 5.3.2** and **Table 5-6,** respectively. Groundwater users are described in **Section 5.2.**

Table A2-4 (Continued)
Summary of AGE Consultants Stage 1 Independent Peer Review Findings [20 December 2019]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
173	AGE [86]	*Extinction depths for the evaporation package are to be varied spatially based on mapped vegetation types. Hydraulic parameters for Quaternary strata will also be varied spatially based on mapping. It is not clear from the information provided whether or not spatial variability is to be incorporated into other layers. However, it is recommended that some spatial variability in other parameters is incorporated into the model via the use of pilot points.*	The adopted evapotranspiration rates and extinction depths within the model domain are outlined in **Table 7-7**. Spatial variability has been incorporated in other layers in the updated groundwater model via the use of pilot points.
174	AGE [87]	*As per the CDM Smith model, both steady state and transient calibrations will be undertaken. However, the transient calibration period will be extended backwards to January 2011 and forwards to September 2019, a period of 8.75 years compared to the previous calibration period of 1.25 years (from January 2017 to March 2018). No information appears to be provided on whether or not recharge will be constant during the transient period or how it will be derived. Modelled stress period lengths during the calibration period are also not stated.*	The simulation period and temporal discretisation is described in **Section 7.6**. Rainfall recharge is applied in the model based on rainfall measurements for each stress period. This allows for flood recharge events (i.e. high rainfall datasets) corresponding with the 2010-11 flood events, and Cyclone Oswald & Cyclone Debbie (**Graph 3-2**) to be considered. The adopted rainfall recharge (%) within the model domain is outlined in **Table 7-6**. It is noted that graphical comparison of the available site-specific monthly rainfall datasets at the Mamelon Station AWS from 2011 to 2019 (corresponding with the calibration period) and Strathmuir (BOM Station 033189) also demonstrates generally consistent rainfall totals and trends (**Graph 3-3**).
175	AGE [88]	*Predictions will be run for the full 18 year mine life using stress periods that are "generally consistent with the calibration scale". It is not clear what the latter means and this should be clarified. Backfilled spoil properties are to be modelled using the TVM package. Justification of the parameters adopted will need to be provided, and where parameters are not derived from measurements, those parameters should be involved in the uncertainty analysis. A 100 year recovery period will also be modelled.*	Comparison of the stress period increments (i.e. 5-yearly, annual, monthly) for the calibration and predictive models are presented in **Table 7-10**. The in-pit backfilling of waste rock, including timing, hydraulic properties and enhanced recharge used in the updated numerical groundwater model are included in **Section 8.3.3**. Time Varying Material (TVM) properties are being applied accordingly to correct the host properties.

Table A2-4 (Continued)
Summary of AGE Consultants Stage 1 Independent Peer Review Findings [20 December 2019]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
176	AGE [89]	*A series of other modelling assessments are also proposed including seepage/solute transport modelling, cumulative impact assessment (including historic mine workings), sensitivity analysis (including identifiability) and uncertainty analysis. No further details on these assessments are available at this time, however it is noted that these are generally essential in meeting the regulator/stakeholder requirements.*	Noted and agreed. Based on predicted drawdown extents and conceptualisation, comparisons of post-mining heads with end of calibration heads has been used *in lieu* of detailed seepage fate/solute transport modelling (**Table 7-1**) and is presented **Section 8.9.** Background to the historic mine workings is provided in **Section 3.4.5** and cumulative impacts described in **Section 8.10**. **Figure 7-5** shows the results of the pre-calibration run, as to does **Graph 7-3**. Limitations and Uncertainty Minimisation is discussed in **Section 8.12**.

Table A2-5
Summary of AGE Consultants Stage 2 Independent Peer Review Findings [14 February 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
177	AGE [90]	*1.6 Are the planned limitations and exclusions of the model stated? No.*	Refer to **Sections 7.7.1 and 8.12** which describes the planned limitations, recognising that the stream flow gauges were installed in September-October 2019 and no flow events were recorded to the end of 2019 post-installation. Similarly, VWP installations require several months to equilibrate, thus validation opportunity only. Therefore, objective is to present robust uncertainty analysis and allowance for future validation.
178	AGE [91]	*2.2.2 Limited discussion of faults. Further discussion of the large bounding fault clearly shown in Figure 7-2 is likely to be required by the IESC and others. What is the throw of this fault? How much connectivity is there likely to be in the various units across this major feature.*	Refer to **Sections 4.1.4, 5.6.8, 7.4.2, 8.11.3 and 8.12.1**. Additional zoom-in **Figure 4-3[e]** included and discussion expanded to describe the throw approximate magnitude. The improved numerical model mesh has incorporated the structural interface between Styx Coal Measures and Bowen Basin (Back Creek Group and Carmila Formation), generally consistent with 1:100k geology mapping and with input from CQCPL's geologists. Lateral connection groups have been used to create horizontal flow connections across the mapped faults. Sensitivity and uncertainty analyses explore alternative hydraulic properties along the faults; these are discussed in **Section 8.11.3**.
179	AGE [92]	*2.2.4 confined or unconfined flow and the variation of these conditions in space and time? Not specifically discussed in any detail. Could be added to a summary table in the concepts section confirming which units are confined, unconfined, fractured, porous etc.*	Refer to **Sections 5.4, 6.1.1 to 6.1.3 and 6.3**. Variation of conditions (e.g. historic workings) is also discussed in **Section 3.4.5**. Unconsolidated and consolidated aquifers, consistent with the *Water Act 2000* bore threshold triggers are discussed in **Section 8.5**. Discussion relating to the Back Creek Group and its sub-crop west of the tenement, versus other areas at depth, is also provided in **Section 8.5.4**.
180	AGE [93]	*2.3.1 It is not clear how the adopted rainfall recharge rates outlined in Table 7-5 have been derived. In the absence of any reference to recharge calculations (e.g. soil moisture deficit calculations, chloride mass balance estimates or water level fluctuations) it would appear the values adopted have been assumed or possibly taken from the CDM Smith report. The reporting (e.g. section 7.5.4) also alludes to the importance of flood recharge and uses this to justify higher recharge rates to alluvium but doesn't present any estimates of likely volumes associated with this recharge source. Annual fluctuations in shallow Quaternary monitoring bores may provide some actual data on possible rates.*	Recharge from rainfall has been adopted consistent with the previous CDM Smith model values, with changes recognising the peer review comment that the 0.6% value used previously was considered low based on modelling experience. As referred, Section 20.5.6.6 of SEIS Chapter 10 – Groundwater (CDM Smith, 2018), recharge estimates were originally derived using the chloride mass balance method (**Section 7.5.4**). Footnotes have been added to **Table 7-6**. Analysis of rainfall datasets from regional BOM meteorological stations and the Mamelon Station datasets has been undertaken and is presented in **Section 3.1.1**. Secondly, flood recharge is recognised and events occurring during the calibration period have been analysed based on available datasets. In the extended calibration period (from 2010-2019) rainfall recharge is applied in the model based on rainfall measurements for each stress period which allows for flood recharge events (i.e. high rainfall datasets) corresponding with the 2010-11 flood events, and Cyclone Oswald & Cyclone Debbie (**Graph 3-2**) to be considered. As for the adopted % recharge modelled, these are considered reasonable considering the model calibration performance statistics in **Section 7.7.4** and **Graph 7-3**. Given the extended below average rainfall conditions which occurred during the refined calibration period (to Sep-Oct 2019), actual data on possible rates are not available for Quaternary monitoring bores for comparison, nevertheless future validation can otherwise confirm.
181	AGE [94]	*2.3.2 river or lake stage heights. Surface water level and flow monitoring installed at two sites on the Deep and Tooloombah Creek (sections 3.3.3 and 3.3.4). It is not clear whether/how this data has been used for model calibration*	No flow events were recorded to the end of 2019 post-installation of the gauging stations in September-October 2019, and therefore not included in the calibration datasets (to end of Q3 2019). Subsequent flow events in January-February 2020 allow for future model validation. River stage heights are applied in the numerical groundwater model and are shown on **Figures 7-4 and 7-5**.

Table A2-5 (Continued)
Summary of AGE Consultants Stage 2 Independent Peer Review Findings [14 February 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
182	AGE [95]	*2.3.3 groundwater usage (pumping, returns etc). Data on existing registered bores has been collated, as summarised in Table 5-6 and includes a number of bores used for water supply. No map of the location of these bores appears to be presented and it is not clear whether or how these bores have been included in the numerical model.*	The location of the bores are shown on **Figure 5-2** and are included in the groundwater model. **Section 8.7.1** (**Graph 8-5**) provides model predicted drawdown at identified private landholder bores in the vicinity of the CQC Project. As tabulated in **Table 8-4**, with the exception of those listed in the table all other identified bores (and database search records) are predicted to have 0.0 m (<0.5 m) predicted drawdown.
183	AGE [96]	*2.3.4 BOM evapotranspiration data collated. But no attempt to map and or quantify evapotranspiration losses from high water table areas for later comparison with modelled estimates which are very high (see comment 4.7).*	BOM evapotranspiration data has been collected and analysed in **Section 3.1.2 and Section 7.5.5**. Comment 4.7 is discussed separately, but as discussed in **Sections 6.3.4 and 6.3.5** the average areal actual evapotranspiration (annual) for the CQC Project and surrounds is estimated to be approximately 715 mm/year (**Figure 3-3**) and is generally equivalent to the recorded average rainfall. Modelled estimates by comparison are approximately 1.3% of this value.
184	AGE [97]	*2.4.1 selection of representative bore hydrographs. Whilst tables are provided there is no map showing the location of monitoring points in each 'aquifer' group (i.e. Cenozoic, Styx Coal Measures and underlying units). Chapter 5 in the report refers to a number of CDM Smith plots showing monitoring locations and groundwater levels. However, this chapter also suggests that additional data is now available. Whilst we note that the objective of the report is to respond to submissions cross referencing key information in other reports makes review of the document somewhat challenging.*	Representative bore hydrographs are presented in **Attachment 8**. Bore locations are shown on **Figures 5-1[a]-[c] and 5-2**. Aquifer groups are clearly discussed and tabulated throughout the report maintaining a consistent colour scheme (**Attachment 4**). Reference to CDM Smith (2018) reports is necessary, however where possible all key information and additional datasets are presented in support of the improved numerical groundwater model.
185	AGE [98]	*2.4.4 watertable maps/piezometric surfaces? Reference made to maps in CDM Smith but report also suggests that more data is now available so these may need updating or perhaps add a comment that since levels are relatively static an update is not required? See also comment 2.4.1 above.*	Model layer head plots are presented for each layer in **Attachment 13**. Inferred Groundwater Level (Phreatic Surface) in Cenozoic Deposits and Regolith is presented in **Figure 5-3**. Estimated depth to groundwater is shown on **Figure 5-4**. The pre-calibration model runs showing groundwater levels (mAHD) in 1919, 1964, 1969 and 2019 are presented on **Figure 7-8**.

Table A2-5 (Continued)
Summary of AGE Consultants Stage 2 Independent Peer Review Findings [14 February 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
186	AGE [99]	*2.4.5 If relevant, are density and barometric effects taken into account in the interpretation of groundwater head and flow data? No corrections applied for highly saline water reported to be present with the Qpa. Justification of why this doesn't matter might suffice. Also influence of saline wedge on discharge to coastal area does not appear to have been discussed or represented in the model in any way.*	Refer to **Section 6.3.2** for Ghyben-Herzberg Relationship discussion and formula considering freshwater and saltwater density. GES barometric adjustments made for dataloggers WMP29A, WMP04 and WMP05) and vibrating wire piezometers at WMP31. As demonstrated in **Section 5.5**, salinity (EC) varies across the hydrogeological units, and with time, and as such density differentials are less definitive. As described in **Section 6.3.2**, the historic workings downstream of the CQC Project have been represented in the model, and recognises the higher EC recorded at WMP13. Tidal influence is discussed specifically in **Section 3.3**. **Figures 3-9 and 8-6** demonstrate the extents of storm tide inland and aerial photograph at a low tide (Rosewood Island) respectively.
187	AGE [100]	*2.5.3 location of diffuse discharge areas? Isotopic sampling and groundwater level observations suggest high value wetland sites and semi-permanent pools are not groundwater dependent and yet modelling suggests that evapotranspiration is the dominant water balance component. The numerical model therefore suggests that substantial evaporation of groundwater is occurring, presumably a large portion of which is from low lying 'wetland' and river areas? If vegetation within wetland areas is sustained by groundwater then are they not by definition groundwater dependent to a degree? There may be an inconsistency between the conceptual and numerical models in this regard. See also comments 2.8 and 4.7 below.*	Evapotranspiration processes are described in **Sections 3.1.2, 6.3.3 and 7.5.5**. Note that two rates are used, including a higher rate for mapped Qhe areas multiplied by a conversion factor for lake evaporation. Application of linear reduction in evapotranspiration rates from the surface has been applied and extinction depths generally consistent with Canadell (1996) based on maximum rooting depths as shown on **Figure 7-6**. Depth to groundwater in WMP25 and WMP27 (**Table 5-6 and Figure 6-5[a&b]**) demonstrate depth to groundwater is beyond the evapotranspiration extinction depths. There is not an inconsistency between the conceptual and numerical models as demonstrated on **Figures 7-6 and 7-7**. Evapotranspiration as a water balance component (**Section 7.5.5**) has been shown separately to be spatially associated with areas in the estuarine alluvium and some in the southern tertiary area within the model domain. Depth to water table in many areas in the vicinity of the CQC Project are beyond 10 m and therefore of no consequence. As shown on the model output included as **Figure 7-11**, modest rates of ET occur along watercourses as expected.

Table A2-5 (Continued)
Summary of AGE Consultants Stage 2 Independent Peer Review Findings [14 February 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
188	AGE [101]	*2.6 Is the measurement error or data uncertainty reported? Measurement error for directly measured quantities (e.g. piezometric level, concentration, flows)? Spatial variability/heterogeneity of parameters? Interpolation algorithm(s) and uncertainty of gridded data? Not obviously discussed in reporting provided?*	Measurement error and data uncertainty is discussed in **Section 8.12.3**.
189	AGE [102]	*2.8 Is there a clear description of the conceptual model? A reasonably clear description of the hydrostratigraphic units present is provided in Section 6 along with their properties. However some key concepts are not discussed in Section 6. In particular there is little to no discussion on the location and/or volume of groundwater discharge. Given that neither the wetlands or rivers are thought to be groundwater dependent where is GW discharge occurring to? Presumably the estuary? If so what is the conceptual model of discharge to the estuary? Submarine or coastal fringe? What role does the saline wedge play in limiting the effective transmissivity of the strata present in the coastal fringe? How has this been simulated in the numerical model? See also comments 2.5.3 and 4.7.* *Parameter ranges used for model calibration are also not reported.*	A clear description of the concept model is presented in **Section 6.3**. Additional localised conceptualisation (eco-hydrogeological) has been provided in **Section 6.3.3**. The conceptualisation describes the ongoing recovery as a consequence of historic mining at Bowman and Ogmore in the downstream reach of the Styx River (**Section 6.3.7**). **Section 7.7.6 (Table 7-17)** is presented to be consistent with the available datasets and model conceptualisation noting that there is assumed a constant/fixed head boundary condition at the model boundary and river stage conditions applied. **Graph 7-5** demonstrates how baseflow/leakage interactions change with time in the model. Refer also to the post-mining groundwater model head gradients presented on **Figures 8-6[a-f]** in support. Parameter ranges used for model calibration have been reported in detail in **Section 7.7.3** (**Tables 7-12 and 7-13**).
190	AGE [103]	*2.8.1 Is there a graphical representation of the conceptual model? A single very small EW conceptual section through in the proposed mining area (Figure 6-1) is provided showing the disposition of layers. Other conceptual sections showing the nature of potential SW-GW interactions i) along Deep Creek and Tooloombah Creek; ii) wetland areas and iii) with the Styx River Estuary/coast would be useful.*	The Simplified Hydrogeological Units Conceptual Model (**Figure 6-1**) has been enlarged (A4-Landscape). Nature of potential SW-GW interactions are presented in CDM Smith (2018). Additional conceptualisations have been included: • Regional conceptualisation for Styx River catchment to Broad Sound/Coast (**Figure 6-2**) • Preliminary Eco-Hydrological Conceptualisation including Tooloombah Creek Pinch Point (**Figure 6-4**) • Wetland 1 and Wetland 2 Conceptualisations (**Figures 6-5[a&b]**) • Ghyben-Herzberg Relationship and Flow Pattern Schematisation (**Figure 6-11**)
191	AGE [104]	*2.9.1 Are the relevant processes identified? Not all processes are identified and discussed (see comment 2.8 above)*	See response above.

Table A2-5 (Continued)
Summary of AGE Consultants Stage 2 Independent Peer Review Findings [14 February 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
192	AGE [105]	*2.9.2 Is justification provided for omission or simplification of processes?*	The simplification of processes are described in **Section 6.3**.
193	AGE [106]	*2.9.3 Have alternative conceptual models been investigated?*	**Section 6.3** refers to the alternative CDM Smith Conceptual Hydrogeological Model. The Broad Conceptualisation for Basement Rock and Freshwater-Saline Water Interface is also provided in **Section 6.3.1 and 6.3.2**. Reference to contemporary eco-hydrogeological models are also referred to (**Figures 6-4[b][i]-[iv]**)
194	AGE [107]	*3.1 Is the design consistent with the conceptual model? As discussed above (comment 2.8) some elements of the conceptual model (especially discharge processes) are not described. The degree of consistency with the numerical model cannot therefore be assessed in some instances. In another instance clear descriptions of model boundary conditions etc are also not provided which also makes a comparison of the models difficult.*	**Section 7.0** describes and provides references back to the available datasets and concepts (in **Sections 3.0, 4.0, 5.0 and 6.0**) to demonstrate the design is consistent. Evapotranspiration processes are described in **Sections 3.1.2, 6.3.6 and 7.5.5** to demonstrate consistency. Model boundary conditions are provided on **Figure 7-6**. The CQC-LF3 Groundwater Prediction Model Files have been provided to assist with the review. **Section 7.7.6 (Table 7-17)** is presented to be consistent with the available datasets and model conceptualisation noting that there is assumed a constant/fixed head boundary condition at the model boundary and river stage conditions applied. **Graph 7-5** demonstrates how baseflow/leakage interactions change with time in the model. Refer also to the post-mining groundwater model head gradients presented on **Figures 8-6[a-f]** in support.
195	AGE [108]	*3.2.1 Are the numerical and discretisation methods appropriate? Although not stated in the report the modelling code is understood to be MODFLOW USG. Although not specifically stated the mesh design is thought to have been undertaken using Algomesh. Reporting should confirm what code has been used and how the mesh design was undertaken.*	Described in **Sections 7.2.2, 7.2.3 and 7.2.4**. The CQC Project numerical groundwater model has been developed using MODFLOW-USG (UnStructured Grid). HydroAlgorithmics' AlgoMesh software has been used to generate the mesh for the UnStructured Grid for MODFLOW-USG. The numerical groundwater model was run with USG-Transport (Panday, 2019), an advanced version of the MODFLOW-USG code, using its Sparse Matrix Solver (SMS) package for the iterative numerical solution.
196	AGE [109]	*3.3.3 layer geometry? The distribution of layers within the modelling domain appears to be consistent with the regional geology mapping and a number of additional layers have been incorporated into the model. However, further discussion of how the faults shown in Figure 7-6a and other maps have been represented in the model. The existing text in Section 7.4.2 alludes to the possible use of non-neighbour connections which given the apparent throw of the fault shown in Figure 7-2 seem likely to be required. How are these faults dealt with in the calibration?*	For description of faults, refer to **Section 4.1.4, 5.6.8, 7.4.2, and 8.12.1**. The structural setting including regional and local faults are described in **Sections 4.1.4 and 4.1.5**. The improved numerical model mesh has incorporated the structural interface between Styx Coal Measures and Bowen Basin (Back Creek Group and Carmila Formation), generally consistent with 1:100k geology mapping and with input from CQCPL's geologists. Lateral connection groups have been used to create horizontal flow connections across the mapped faults. Sensitivity and uncertainty analyses explore alternative hydraulic properties along the faults; these are discussed in **Section 8.11.3**. As described and presented in **Section 5.1.3** and **Attachment 4**, CQCPL has installed a VWP north-east and east of the fault to validate the stratigraphy (Back Greek Group) and pressures at depth to below the base of the CQC Project open cut.
197	AGE [110]	*3.4.3 time steps? Not stated.*	Adaptive time steps are appropriate (**Section 7.6.2**).

Table A2-5 (Continued)
Summary of AGE Consultants Stage 2 Independent Peer Review Findings [14 February 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
198	AGE [111]	*3.5.1 Is the implementation of boundary conditions consistent with the conceptual model? Modelled boundary conditions are presented in Figure 7-1. However, this is a very small map of a large area which also has no legend. The low/poor resolution of this figures means it is not sufficient to see the precise location of the various model boundary conditions. A larger map is recommended with a legend showing i) no flow boundary cells; ii) constant head boundary cells; iii) river boundary cells which act like drains (i.e. stage = 0); iv) other river boundary cells (i.e. with stages >0).* *Not clear whether take from existing landholder bores has been modelled or not.*	Modelled boundary conditions are presented on **Figure 7-4**. Existing landholder bore users are not explicitly modelled, however was considered as part of uncertainty analysis (**Section 8.12.4**). Based on the results of the numerical groundwater model outputs, review of the BH20-BH01X-BH16 monitoring, and consideration that use in the vicinity of the CQC Project is limited due to generally poor quality beyond the watercourses, a specific sensitivity was not undertaken as it was unlikely to be of any consequence when considering other model parameterisation.
199	AGE [112]	*3.5.2 External boundaries are sufficiently far away from the proposed development area that they are unlikely to have a significant effect on predictions. It is also inferred from Table 7-4 that river cells in close proximity to the proposed open pit are parameterised with stage = 0. This should be confirmed, however, since the use of constant head river boundary cells close to the pit could limit predicted drawdown cones etc.*	Noted and agree. River cell stage conditions are presented on **Figure 7-4** and Stage = 1 m along the corresponding reach of Tooloombah Creek (not zero) (**Section 7.5.3** and **Table 7-5**).
200	AGE [113]	*3.5.3 Although not clearly stated (section 7.5.4) it is inferred that a transient recharge boundary condition is being applied to the model and that this is likely to based on constant proportion of monthly rainfall. Initial rates prior to calibration in the model appear to have also been assumed although they may be based on Chloride Mass Balance results undertaken by CDM Smith (2018)? If not already undertaken by CDM Smith consideration should be given to undertaking soil moisture deficit, chloride mass balance or water level fluctuation calculations to validate the current estimates.*	Transient recharge is applied based on a constant proportion of rainfall for the averaging period. This is evident and discussed in **Sections 7.7.2 and 7.7.4**. As referred, Section 20.5.6.6 of SEIS Chapter 10 – Groundwater (CDM Smith, 2018), recharge estimates were originally derived using the chloride mass balance method. However, subsequent peer review suggested the 0.6% value used previously was considered low based on modelling experience. Footnotes have been added to **Table 7-5**.

Table A2-5 (Continued)
Summary of AGE Consultants Stage 2 Independent Peer Review Findings [14 February 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
201	AGE [114]	*3.7 Is the numerical solution of the model adequate? Not reported.*	The numerical solution method/solver is described in **Section 7.2.4** and presented in **Table 7-2**.
202	AGE [115]	*4.1.1 Calibration to observed borehole groundwater level data only. No calibration to observed head differences at nested locations, to or observed levels in semi-permanent pool monitoring locations on the Deep and Tooloombah Creek.*	Groundwater head observation data has been used in the calibration as demonstrated clearly by **Graph 7-1**. A map of average transient residuals to highlight the calibration performance across the model domain is presented in **Figure 7-9[a]. Extrapolated residuals are also presented on Figures 7-10[a-c].** A comparison of the computed groundwater levels for the WMP Series Bores and select Landholder Bores with temporal measurements is also presented in **Attachment 8**. As demonstrated, the simulated groundwater levels compare very well for many observation bores and display an overall reasonably good trend for the extended below average rainfall conditions particularly in the surficial units (Cenozoic deposits and regolith) for most bores. It is noted that additional head observations are available on Tooloombah Creek at the pool (and invert) upstream (and downstream) of the Gauging Station, and upstream (TC) based on survey level measurements by CCS Surveys Pty Ltd (2020). It is understood more refined site-specific analysis is being considered separately by Orange Environmental and Eco Logical Australia Pty Ltd (2020). [*NB: Head differences are an element of 4.1.3 below*]
203	AGE [116]	*4.1.2 No calibration to flux observations. Data are recognised to be limited but time series data are available for two new monitoring sites on the Deep and Tooloombah Creek which suggest zero flow on each day. Actual evapotranspiration estimates could/should also be developed for model calibration/validation purposes, especially given the dominance of EVT in the modelled water balance (see comment 4.7 below).*	Time series data are now available for two new monitoring sites on the Deep Creek (**Graph 3-8**) and Tooloombah Creek (**Graph 3-6**) which suggest negligible to zero flow during the extended calibration period toward the end of the extended period of below average rainfall (September-October 2019). This is consistent with absence of pool water sampling opportunities at several locations in Deep Creek which from July 2019 were no longer available during the AMEC (2019) investigations. In January-February 2020, flow data has since been recorded and could be considered in future groundwater model validation. Response to comments relating to Actual ET estimates is provided below. The dominance in the water balance is addressed separately above (**Figure 7-11**).
204	AGE [117]	*4.1.3 Other: environmental tracers, gradients, age, temperature, concentrations etc.*	Refer to **Sections 4.3** (TEM Survey), **5.5.8** (environmental isotopes), **6.3.2** (freshwater-saltwater interface – salinity concentrations) and **7.7.4** (vertical head gradients). **Figures 8.5[a-f]** also present post-mining head gradients.
205	AGE [118]	*4.2 Model parameterisation largely thought to have been undertaken using pilot points, although this is not clearly stated anywhere and may not be the case in all layers/cases.*	Spatial variability has been incorporated in other layers in the updated groundwater model via the use of pilot points and is stated in **Section 7.7.3** and presented in plots in **Attachment 12**. It is also evident in the ranges (and log mean) presented in **Table 7-12** for each zone.
206	AGE [119]	*4.2.4 Which methodology is used for model calibration?*	**Section 7.7.1** describes that both manual (initially) and automated calibration methods have been used, with manual calibration only used initially to assess model stability, before then being automated using the PEST suite of software (Doherty, 2015).
207	AGE [120]	*4.3 Is a sensitivity of key model outcomes assessed against?*	**Refer to Sections 8.11.2 and 8.11.3.**

Table A2-5 (Continued)
Summary of AGE Consultants Stage 2 Independent Peer Review Findings [14 February 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
208	AGE [121]	*Are multiple methods of plotting calibration results used to highlight goodness of fit robustly? Is the model sufficiently calibrated? Spatial plots of residuals are shown in Figure 7-6 and Figure 7-7. However maps showing modelled heads in key hydrostratigraphic units are not presented. Modelled water table is shown in Figure 5-1 and some data are also shown in Figure 7-5. However, these maps are very small and it is not clear what exactly is being plotted in either case. Plots of modelled heads will likely assist with understanding where the high evaporation losses and inflow from the coastal boundary condition is occurring (see comment 4.7 below).*	Refer to **Attachment 13** which presents model head plots at the end of calibration in all layers. Zoomed in and detailed maps are provided in the predictive assessment (**Section 8**) (**Figures 8-3, 8-5 and 8-6**). EVT losses and coastal boundary conditions are addressed separately above.
209	AGE [122]	*4.6 Are the calibrated parameters plausible? Presented in Tables 7-11 and 7-12. Values are plausible although anisotropy values for many layers (especially interburden) are lower than those estimated using many contemporary models of similar sedimentary sequences. Parameter ranges adopted for calibration are also not reported and there is no commentary on whether or not calibrated parameters are at the adopted upper or lower bounds. Reference to initial anisotropy values (reported in Table 6-4) are also low and hence it may that these values have changed little during the calibration since Kv parameters have low identifiability. A sensitivity or identifiability analysis would help to investigate this further. The inclusion of additional head difference calibration targets may also assist.*	Parameter ranges adopted are included in **Tables 7-12 and 7-13**. Refer to Uncertainty Analysis.

Table A2-5 (Continued)
Summary of AGE Consultants Stage 2 Independent Peer Review Findings [14 February 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
210	AGE [123]	*Are the water volumes and fluxes in the water balance realistic? Transient modelled water balance results are reported in Table 7-14. The dominant modelled output is reported to be Evapotranspiration (67.74 ML/day, around 83% of the modelled total). Whilst this is possible, further information on where these losses occur within the modelling domain is required (e.g. map showing the rate of EVT loss from each model cell). Further validation of this loss is also recommended (e.g. through comparison with estimated losses from areas where evaporation of groundwater is actually occurring). Noting that the conceptual model for the Project area also states that neither the wetlands or local creeks are groundwater dependent and hence substantial EVT losses should not be occurring from these areas in the model. Further justification should also be provided on the high 8m extinction depth assumed for parts of the model domain (Table 7-6) as this is an obvious potential source of the large modelled losses. Perhaps related to the high EVT losses the relatively large volume (19.064 ML/day) of water flowing into the model via the coastal constant head boundary is also surprising given the current lack of development of the area. Discharge to, rather than from, the coastal boundary would normally be expected. Again maps showing where this discharge occurs would be useful. In reality a large part of the EVT demand will be met be flood recharge events which occur periodically. What is the effect of the exclusion of this input from the modelled water balance?*	Relevant mechanisms are described and presented (EVT Extinction Depth – **Figure 7-6**) and is presented on **Figure 7-11**. It is noted that during the conceptualisation (**Section 6.3.7**), approximately 74% of the previous groundwater model outputs in the water balance related to ET, so it is considered reasonable, considering the north-eastern extension of the model domain where higher evaporative surface is made available near the estuary. Importantly, note the topographic and groundwater water elevations (1 mAHD contour) shown on **Figure 4-10** at the confluence of Granite and Montrose Creeks and the Styx River, immediately upstream of the railway bridge / Broad Sound Fish Habitat Area (Plan FHA-047) (**Figure 3-5**). Considering the model domain (Styx River catchment) is 1,600km^2 and the Mamelon Station recorded evaporation has been up to approximately 1,115 mm/year between 2012-2018) this equates to approximately 50 ML/day if applied on average across the domain. Importantly the maximum rate applied is not the pan evaporation rate which, based on the St Lawrence weather station is often 2-3 times greater than ET. That is, the 67 ML/day is still well within the potential value and therefore considered realistic. **Figures 8.5[a-f]** also present post-mining head gradients which assist with understanding vectors in the north of the model domain.

Table A2-6
Summary of AGE Consultants Stage 3 Independent Peer Review Findings [7 May 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
211	AGE [124]	*2.1.1 Surface Water – Groundwater Interaction* *Further justification (or revision) of the proposed use of MODFLOW drains to simulate surface-groundwater interaction was recommended.*	See previous responses in **Table A2-4** and note that additional sensitivities for the Tooloombah Creek boundary condition as well as river bed conductance were completed in **Section 8.11.6**.
212	AGE [125]	*2.1.2 Saline – Freshwater Interface* *Further consideration of the possible effect of groundwater salinity variations on groundwater flow patterns and consideration of the potential impacts of the development on the position of the freshwater/saline interface.*	See previous responses in **Tables A2-4 and A2-5** and the Ghyben-Herzberg relationship is specifically discussed in **Section 6.3.2.** It is noted that data adjustments were not made to maintain consistent presentation of recorded level datasets, particularly given the variability of the recorded salinities throughout the Cenozoic sediments and Styx Coal Measures (which are not freshwaters), and the presence of the historical mine workings between the CQC Project and the coastline, which included development beneath the Styx River. Importantly, it is recognised that there are many other factors which effect the interface location including topography, geology architecture (geometry), recharge, vegetation cover as well as historic anthropogenic use.
213	AGE [125]	*2.1.3 Baseline Data Availability* *Agency review of previous model iterations all identified the existing baseline data set as being inadequate.* *- the number and length of groundwater level records available for the basement and coal measures;* *- hydrochemistry data for deep bores to define the saline-groundwater interface; and* *- flow data for Deep Creek and Tooloombah Creek ideally upstream and downstream of the site to confirm surface water – groundwater interaction concepts and provide data for calibration.*	Responses to previous Agency review comments are provided in **Attachment 1**. See also previous responses in **Tables A2-4 and A2-5** (with reference to **Sections 5.0 and 6.3.2**). A targeted review of groundwater quality of the shallow and deep bores between the CQC Project and the coastline is provided in **Section 6.3.2**. Tide elevation monitoring was established at Ogmore Road bridge (**Section 3.3.2**). TEM survey was completed and is presented in **Attachment 5**. CQCPL has continued to augment groundwater level and quality baseline datasets in 2019/2020. Additional groundwater monitoring locations were installed in the basement and coal measures consistent with the recommendations (i.e. WMP31, WMP32^{A}, WMP21B and WMP06D), dataloggers installed WMP04, WMP05, WMP29A and WMP06. Surveyed flow gauging stations on Tooloombah Creek (ToGS01) and Deep Creek (DeGS01) continue to collect pool elevation and water quality, and surface water monitoring location (To4) further upstream has been established. Data collected from the survey pool elevations have since been used for model validation in **Section 7.8**.
214	AGE [126]	*2.1.4 Model size* *In terms of the overall size of the model a relatively large model of up to 1 million cells was being proposed during Stage 1. As described in Section 7 of the HA report a model comprising some 497,029 active cells was ultimately developed. Accordingly, the model does run relatively slowly using a standard version of MODFLOW USG and standard specification desktop PC. For instance the predictive run provided with the model files takes around 10 hours to run on a PC with an i5 7500T 2.7 Ghz CPU processor and 8 Gb RAM. The same run, however, completed in around two hours using a proprietary GPU based solver developed by HA making the model much more manageable in terms of size and run times.*	Comment noted. See previous responses in **Table A2-4.**

Table A2-6 (Continued)
Summary of AGE Consultants Stage 3 Independent Peer Review Findings [7 May 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
215	AGE [127]	*3.1 Review of Hydrogeological Conceptualisation* *The hydrogeological conceptualisation is presented in Section 6 of the HA report. This section includes a generally clear summary of the distribution and thickness of hydrostratigraphic units in the area and their hydraulic properties. There is an appropriate focus on surface water and groundwater interactions along the two creeks immediately adjacent to the proposed mining activity. The presented conceptual model is plausible and has identified the components responsible for bulk water movement into, through, and out of the aquifers associated with the CQC project.*	Comments noted.
216	AGE [128]	*3.1.1 Data Availability* *Whilst a number of data limitations are discussed the report would benefit from a section dedicated to discussion of data limitations.*	**Section 8.12** is a dedicated section which discusses the limitations in the context of what opportunities there are to minimise uncertainties.
217	AGE [129]	*3.1.1 Data Availability [Cont.]* *Substantial additional data has been collected since completion of the previous groundwater impact assessment (GIA) for the project…*	Comment noted.
218	AGE [130]	*3.1.1 Data Availability [Cont.]* *Substantial additional data has been collected since completion of the previous groundwater impact assessment (GIA) for the project… Water quality monitoring has also continued in these and other existing facilities and hence sub-surface salinity variations are also now better understood. Accordingly, the three main data deficiencies identified in above in Section 2.1.3 have all been addressed to some extent.*	Comment noted.
219	AGE [131]	*3.1.1 Data Availability [Cont.]* *Remaining data limitations with the potential to affect the current conceptualisation include:*	The available flow/pool elevation data along Tooloombah Creek and Deep Creek has been used in the model validation as requested (**Section 7.8.1**). But it is noted that based on the timeframes that the groundwater model operates, and available observation and anecdotal records, it is considered appropriate to represent this as an effective constant head (Stage = +1m). Nevertheless, a separate sensitivity applying stage = 0 m (**Section 8.11.6**) has been conservatively applied to demonstrate the effect of applying constant conditions.

Table A2-6 (Continued)
Summary of AGE Consultants Stage 3 Independent Peer Review Findings [7 May 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
219	AGE [131] [Cont.]	*[Cont. Above]* *- the relatively short period of record currently available for the gauges on Tooloombah Creek and Deep Creek, the monitored period only includes a single recent flow event;* *- flow gauging on Tooloombah Creek upstream of the proposed mine workings; and* *- a historic groundwater level data set comprising predominantly monthly manual dips, groundwater level loggers have currently only been installed in a small number of recent installations.*	Justification for not applying the streamflow package has been included, and it is recognised that upstream monitoring opportunities for confirming the surface water-groundwater conceptualisation (i.e. during future flood events in the vicinity of WMP06) are available, and monitoring equipment is in place. This may provide the future opportunity to adjust river bed conductance to reflect the effect of flood recharge for model validation. Surface water monitoring at To4 upstream has also been established by CQCPL. Separate responses to the comment that a 2nd Tooloombah Creek upstream gauging station is also required should be referred to WRM Water & Environment (2020), as an AWBM model has since been developed. Groundwater level loggers have been installed in groundwater monitoring bores (WMP04, WMP05, WMP06 and WMP29A) which would be considered most likely to record a response following recharge events given proximity to paired surface water monitoring and would be beneficial in support of the conceptualisation. Installation of a datalogger has also been included in WMP31 for the four (4) vibrating wire depths. Installation of dataloggers across the extensive network of groundwater monitoring bores, whilst ideal, would not present any short term benefits as it has been demonstrated in the past 2 years (see **Attachment 8**) that the monthly recordings of relatively stable groundwater levels bores are adequate to investigate trends, where any.
220	AGE [132]	*3.1.2 Hydrostratigraphic Units* *The segregated hydrostratigraphic units (HSU) adopted in the conceptual model appear plausible and represent an improvement on the previous numerical model conceptualisation. In particular separate numerical model layers have been used to represent the three major coal seams (the Red Lower 2, Blue Lower 2 and Violet Lower 2) as well as overburden, interburden and underburden units. In total seven layers have been used to represent the Permian Styx Creek Coal Measures with a further four layers for the overlying Quaternary and Tertiary aged strata and three layers for the underlying Back Creek and Volcanic groups.*	Comment noted. Note the model layers are also shown on **Figure 7-2**.
221	AGE [133]	*3.1.3 Aquifer Parameters* *Substantial additional field hydraulic conductivity and storage data have been collected for the site since the previous EIS iteration, including continuous packer testing and laboratory analysis of core samples taken from the Styx Coal Measures to the base of the proposed open cut. …*	Comment noted.

Table A2-6 (Continued)
Summary of AGE Consultants Stage 3 Independent Peer Review Findings [7 May 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
222	AGE [134]	*3.1.3 Aquifer Parameters [Cont.]* *Given that the unconsolidated strata present in the area are considered to be relatively poor aquifers and include relatively high proportions of clay then relatively low specific yield values are justified to some extent. However, adoption of an upper bound specific yield value of say 10% for unconsolidated strata during calibration would have been preferable. Sensitivity of model predictions to this parameter has been assessed further as part of the uncertainty analysis (Section 3.2.10).*	Comment noted. Refer to **Section 8.11**.
223	AGE [135]	*3.1.3 Aquifer Parameters [Cont.]* *It is acknowledged that the adoption of relatively low specific yield values will tend to maximise the extent of drawdown all other things being equal and could therefore be argued to be conservative at least from the perspective of modelled drawdown. However, with regard to pit inflows and related volumetric impacts on water courses low specific yield values may result in pit inflows and flow impacts being underestimated.*	Comment noted. Refer also to additional parameter sensitivity for investigating pit inflows (**Section 8.11.6**). The largely unchanged predictions for annual mine inflow (**Attachment 18**) and peak inflow (**Graph 8-6**) demonstrate that direct inflows from Tooloombah Creek in the long term to the open cut pit is unlikely. This support the concept of indirect (i.e. piston-like) groundwater movement effects, as the quantum of predicted inflows to the open cut drains still occurs from water stored in the immediately surrounding rocks.
224	AGE [136]	*3.1.4 Seawater Intrusion and Density Dependent Flow* *At the location of the proposed open cut and based on the Ghyben-Herzberg relationship the saltwater interface is reported to be likely to be between 480-680 mbgl, more than 300m below the base of the proposed open cut. Accordingly it is considered unlikely that the position of the saline interface would be affected by dewatering operations.*	It is noted that the report goes on to state: *However, it is relevantly noted that this conceptualisation assumes the density of freshwater is maintained inland, and it is known the Cenozoic sediments tend to be brackish to saline (Section 5.5.2), so conservatively applying a lesser differential, and a reduced (half) α factor (where r_f ~1.012 gm/cc), the interface would still be in excess of 500 m for a height of free groundwater above sea level of 6.5 m.* It is recognised that there are many other factors which effect the interface location including topography, geology architecture (geometry), recharge, vegetation cover as well as historic anthropogenic use.
225	AGE [137]	*Similarly the coastal boundary is located sufficiently far from proposed open cut that the precise nature and location of this boundary condition, which is largely unknown, are considered unlikely to affect predicted impacts significantly.*	Noted and agreed.

Table A2-6 (Continued)
Summary of AGE Consultants Stage 3 Independent Peer Review Findings [7 May 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
226	AGE [137]	*However, as reported in Section 5.5, many groundwater samples taken in the area in the Quaternary, Tertiary and underlying Permian aged units are highly saline, whilst surface water systems are relatively fresh. These observed density differences and their potential impacts on flows from more saline to less saline areas are not represented in the numerical model and this should be recognised in the reporting as a limitation of the current model.*	As demonstrated by the surface water quality monitoring and TEM survey (**Attachment 8**), freshwaters associated with surface water systems and adjacent alluvial aquifers are very limited. Given the variability of salinity through the hydrogeological units, primarily recognising the geological and geomorphological history (**Section 4.6.1** and **Attachment 6**) of the Styx Basin, as a consequence of rising and falling sea levels in the order of several metres, the supposed effects due to density differences are considered minimal. Nevertheless, a statement has been added to **Section 8.12** accordingly.
227	AGE [138]	*It is not clear from the reporting provided whether or not observed groundwater levels have been adjusted for salinity to produce an equivalent freshwater head. It is understood that such corrections were applied to groundwater levels used during previous iterations of the EIS, so it is possible that appropriate corrections had already been applied to the data used for the current project. Where corrections have been applied then further information should be provided on the methodology used and the assumptions inherent. Conversely if density corrections have not been applied, then this should be justified, as data for a number of bores show very high salinities which may result in potentially significant head 'errors' if they have not been first translated into equivalent freshwater heads.*	Groundwater levels (standpipe depth to groundwater) recordings have been used unadjusted in the reporting and model calibration targets (steady state and transient), and is considered appropriate particularly as explained above, freshwaters associated with surface water systems and adjacent alluvial aquifers are very limited. That is, density corrections (albeit small) have not been applied, but future groundwater model validation exercises could be used if necessary to investigate select groundwater monitoring bores which were to record very high salinities, should substantial head differentials be observed in the future. Nevertheless, the model calibration (**Section 7.7; Graphs 7-1 and 7-2**) without adjustment is considered acceptable.

Table A2-6 (Continued)

Summary of AGE Consultants Stage 3 Independent Peer Review Findings [7 May 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
228	AGE [139]	*3.1.5 Faults* *Hence whilst the fault has not been assumed to be a barrier in the model, the horizontal hydraulic conductivity contrast across it is sufficient to limit the propagation of drawdown impacts (Section 3.2.9).*	Comment noted. Considered and addressed in **Tables A2-4 and A2-5**. Refer to **Section 8.12.1**. Refer also **Section 10.1.9**.
229	AGE [140]	*3.1.6 Surface Water Groundwater Interactions* *Monitoring of levels at the Tooloombah Creek gauge site suggests that the pools here are semi-permanent, declining only very slowly (less than around 0.5m in a three month dry period from mid October 2019 to mid January 2020). Well conceived conceptual diagrams showing groundwater-surface water interactions at Tooloombah Creek under a range of different flow conditions are also shown in Figure 6-4 (i to iv).*	Updated Flow Duration Curves has been provided by WRM Water & Environment (2020) and separate pool analysis conducted. As outlined in **Section 7.8.1**, post model calibration of pool survey levels are now presented, based on survey elevations by CCS Surveys Pty Ltd at five (5) locations in May 2020. At a zoomed-in scale, **Graph 7-7** shows for: • Tooloombah Creek: the applied RIV cell stage (+1 m) is a good fit, whereas the zero stage elevation applied (recommended by the peer review as a model sensitivity run [**Section 8.11.6**]) is lower; and • Deep Creek: the approximate 2 m differential is not unexpected at the higher topographic locations, recognising that the groundwater model groundwater level prediction is at end of calibration period corresponding with extended dry period (Sept-Oct 2019) (and dry observation records), versus surveyed pool levels recorded in May 2020, post the January-February 2020 rainfall events and is consistent with the applied RIV cell stage (0 m). The survey levels have also been used to tie the gauging station streamflow records since installation to mAHD and are shown on **Graphs 5-1 and 5-2** for relative comparison with groundwater levels recorded at WMP05 (Qa) and WMP04 (Qpa).
230	AGE [141]	*Multiple lines of evidence are referenced in the report, including isotopic analysis and groundwater level monitoring, and appear to suggest that the water table is more than 10 m below ground level within these wetland areas. Accordingly, the wetlands are thought to be disconnected from groundwater and largely dependent on surface water sources.*	Comment noted. Separate assessment is also being undertaken by Eco Logical Australia (2020).
231	AGE [142]	*3.1.7 Conceptual Water Balance* *In particular a conceptual model of the key discharge components and their relative magnitudes is not provided.*	The conceptual water balance is considered adequate to support the model design and build. Estimates of evaporation rates and total volumes of groundwater recharge are provided. The key discharge components are shown on **Flowchart 6-1**, with relative magnitudes by arrow heads, and reference is made to the earlier statement that local groundwater tends to mound beneath the hills to the west (**Figure 5-3**), with ultimate discharge to local drainages and eventually to the coast. Reference is also made to prior conceptualisation by CDM Smith (2018) (Section 10.5.6.8 of the SEIS).

Table A2-6 (Continued)
Summary of AGE Consultants Stage 3 Independent Peer Review Findings [7 May 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
232	AGE [143]	*3.2.1 Model Confidence Level* *With regard to the adequacy of the streamflow data set we would argue that the current data should be assessed as being Class 1/2, rather than Class 2/3 as assessed by HA. Whilst two gauges have been installed on Tooloombah and Deep Creek downstream of the proposed workings only a short period of record is currently available and has not currently been used to calibrate or validate the model.*	AGE Consultants appear to have created two new “interim” model confidence categories i.e. “1/2” and “2/3”. That is: 1, 1/2, 2, 2/3, 3. The summary Table A10-1 in Attachment 10 only refers to Class 2 which states: “*Streamflow data and baseflow estimates available at a few points*”. We suggest AGE Consultants correct this statement. The data is available and model validation undertaken at a few points (**Section 7.8.1**) and is therefore Class 2. Given the availability of generated Flow Duration Curves, observed dry records (i.e. no baseflow) and Tooloombah and Deep Creek pool/stage estimates as well as recorded Ogmore Road Bridge (Styx River) depths/elevation, it should not be concluded that there is “*Little or no useful data on river flows and stage elevations*.”
233	AGE [144]	*With regard to the availability of reliable soils and land use data, the HA assessment suggests that the Class 3 requirements have been met. However, as discussed further in Section 3.2.3.3 whilst land-use data is available and is described in Section 3.4 of the HA report it appears not to have been used to parameterise the MODFLOW evaporation package. This has led to the simulation of evaporation losses to 8 m below ground level even in areas which have been cleared for grazing and there are few if any deep rooted trees. Accordingly, this is an area where the requirements of the targeted Class 2 confidence level do not appear to have been achieved.*	The soil mapping data is available and is reported in **Section 4.4,** and as discussed refers to the Qa and Qpa units applied in the groundwater model domain. As previously explained, and then demonstrated by the additional parameter analysis in **Section 8.11.6** there is little to no consequences to drawdown extents and key metrics when applying a reduced evapotranspiration extinction depth in the model across the majority of mapped Cenozoic sediments. This was clearly evident when viewing the CDM Smith prior depth to groundwater contours (Figure 10-96 in Chapter 10 of the SEIS). Regardless of the above, as stated in **Section 6.2.2**, on the basis that irrigation water is not applied on the Mamelon property, this is considered reliable in part of the area and therefore Class 2 is achieved.
234	AGE [145]	*Some parts of Tables A10-1 to A10-5 in the HA report which presents the modellers assessment are also currently marked as being ‘TBC’ and hence we are currently unable to comment fully on this aspect of the reporting.*	**Tables A10-1 to A10-5** have been updated accordingly in advance of the final peer review letter.
235	AGE [146]	*3.2.2 Model Structure* *Given the objectives of the numerical model and the type and setting of the development the choice of MODFLOW-USG is considered sound. Similarly the development of a highly refined mesh in and around the primary areas of interest using HA’s AlgoMesh software is commended.*	Comment noted.

Table A2-6 (Continued)
Summary of AGE Consultants Stage 3 Independent Peer Review Findings [7 May 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
236	AGE [147]	*Both the particular variant of MODFLOW-USG (USG-Transport) used for the project and AlgoMesh are in widespread use within the groundwater flow modelling industry and as such have been found to be fit for purpose for use in EIS and other projects.* *Further utilising MODFLOW-USG capabilities so-called non-neighbour connections have been introduced into the model to allow simulation of areas where hydrostratigraphic units pinch out across mapped faults.*	Comment noted.
237	AGE [148]	*Both the model extent and mesh design are considered to be appropriate based on the predicted extent of impacts. If anything, the model domain is perhaps more extensive than strictly necessary.*	Comment noted. Refer to **Tables A2-4 and A2-5** for previous responses in relation to the model domain. Importantly, this is supportive of matters relating to EPBC Act.
238	AGE [149]	*3.2.3.1 Coastal Boundary Condition* *The surface processes in the tidal zone of Styx River are dynamic, however on the timeframes that the groundwater model operates it is entirely appropriate to represent this as a constant head and evidence is presented to support the adopted 3 mAHD head and extent of the boundary condition.*	Please note the adopted boundary condition in the model was 3.5 mAHD (not 3 mAHD). As demonstrated by the subsequent sensitivity analysis (**Section 8.11.3**) the sensitivity of the bounds from 2 mAHD to 4.5 mAHD was tested and shown to be insensitive at the distance of ~25 km.
239	AGE [150]	*3.2.3.2 Creek Boundary Condition* *The use of the MODFLOW river boundary condition at this location is therefore considered to be defensible, although an additional impact sensitivity run is recommended, as described in Section 3.6.1, to confirm the degree to which model predictions are sensitive to the use of this boundary condition.*	Refer to **Section 8.11.6**. For the purposes of comparison with the results presented for the CQC-LF3 model which applied a stage depth of 1 m along Tooloombah Creek Reach 2 (**Figure 7-4**), all RIV cells along the same reach were changed to a 0 m effective depth. As shown in the key model outputs (**Attachment 18**), in the absence of a stage boundary condition in Tooloombah Creek Reach 2, the maximum predicted drawdown extents conservatively propagate to the north-west, generally along the strike of the coal measures. Changes in key metrics demonstrate the peak mine inflow predictions are substantially the same, and peak baseflow/leakage change predictions along Tooloombah Creek is less, and by comparison to the 99.7% confidence intervals of probability of exceedance is greater than very likely (>90%) (**Graph 8-6 and 8-7**). It is also noted in **Section 7.8.1** (**Graph 7-7**) the surveyed pool levels along Tooloombah Creek in May 2020 (albeit two data points), provides a better fit with a stage depth of 1 m applied.

Table A2-6 (Continued)
Summary of AGE Consultants Stage 3 Independent Peer Review Findings [7 May 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
240	AGE [151]	*All other river cells in the model domain have been parameterised such that they act like drains (by setting the river stage and modelled river bed to the same value) and can only remove water from the model domain. This is considered to be consistent with the ephemeral nature of these creeks, the lack of permanent pools, and in terms of lateral propagation of impacts is also considered to represent a conservative approach.*	Comment noted. Zero baseflow observations are considered a baseflow estimate, and therefore as demonstrated in the commentary "…*baseflow estimates are available at a few points"* and have been used (i.e. Class 2).
241	AGE [152]	*3.2.3.3 Evaporation* *As described in Section 3.4 of the HA report, land use in the model domain is dominated by agriculture (78%) predominantly grazing. However, rather than base modelled extinction depths on land use mapping it would appear based on Table 7-6 in the HA report that they have been based on outcrop geology mapping such that all areas mapped as Qpa, Qr, Qf and Qa on regional geology maps have been assigned extinction depths of 8 m. As shown in Figure 3.1 this results in extinction depths of 8 m being assumed across the majority of the modelling domain, despite clearing of the majority of this area for grazing purposes. We are therefore unable to support the current configuration of the evaporation package and a second impact sensitivity run is recommended as outlined in Section 3.6.2 to confirm the sensitivity (or otherwise) of model predictions and calibration to the current extinction depth assumptions.*	Refer to **Section 8.11.6**. Despite the clear qualitative justification presented in **Section 8.11.4** to apply the extinction depth across the Cenozoic sediments, primarily on the basis that the depth to groundwater table in most areas in the vicinity of the CQC Project are beyond 10 m (which was also consistent with the depth to groundwater maps presented on Figure 10-96 in CDM Smith [2018b] across the Cenozoic sediments), AGE Consultants requested that the numerical model be re-run to quantify the changes. Therefore, the 8 m evapotranspiration extinction depth was applied only where moderate and high potential GDEs had been mapped, and 3 m everywhere else within the model domain (**Figure 8-10**). As shown in the key model outputs (**Attachment 18**), the maximum predicted drawdown extents are largely the same, and the peak mine inflow and baseflow/leakage change predictions are slightly higher than the CQC-LF3 results, but all well within probability of exceedance of 50% (as likely as not) or approaching very likely (90%) (**Graph 8-6 and 8-7**).
242	AGE [152]	*The very high evaporation losses predicted in isolated areas, particularly towards the southern boundary of the domain shown in Figure 3.2, also warrant an explanation.*	The areas relate to the mapped Tertiary sediments in the southern area of the model domain (where the model mesh cells are large and elevations rise). Given distance to the CQC Project, and location at the model boundary, the differentials are not considered to be of any consequence.
243	AGE [153]	*3.2.3.4 Groundwater Extraction* *Existing groundwater extraction from landholder bores has not been included in the model. … . The exclusion of these bores is considered to be a reasonable simplification and unlikely to affect the ability of the model to predict project impacts.*	Comment noted.

Table A2-6 (Continued)
Summary of AGE Consultants Stage 3 Independent Peer Review Findings [7 May 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
244	AGE [154]	*3.2.4 Representation of Dewatering* *As described in Section 8.3.1 of the HA report, advanced dewatering using groundwater extraction bores is under consideration but would involve the construction of sacrificial bores within the proposed open cut footprint, rather than outside it. Accordingly, assuming that these bores are not drilled more than say one year in advance of the proposed open cut then no material effects on either the magnitude or timing of impacts would be expected.*	Comment noted.
245	AGE [155]	*3.2.5 Model Approach and Steady State* *As there is no historic groundwater level data prior to January 2011, then only the steady state model and the second transient model of the more recent period have been calibrated. The transient simulation of the period from 1919 to 2010 therefore acts to provide realistic water levels for the start of the second transient calibration. Both steady state and transient calibration models have been calibrated to groundwater levels only. No flux or head difference targets at nested monitoring locations have been included in the calibration.*	AGE should note that whilst head difference targets were not initially included in the calibration, they were subsequently included in the validation plots **in Section 7.7.4** (**Graph 7-4**). Overall, the vertical head gradients are generally consistent (e.g. upward [negative] simulated gradients = upward [negative] observed gradients; or downward [positive] simulated gradients = downward [positive] observed gradients) or if not, the gradient is very flat (i.e. near the graph centre point 0,0).
246	AGE [156]	*3.2.6. Whilst it is accepted that recharge to such backfill areas will likely by higher than native ground, on account of its relatively high hydraulic conductivity no justification appears to have been provided for the 5% rainfall infiltration rate assumed. Rainfall infiltration rates applied to other zones representing unconsolidated Quaternary strata characterised by even higher hydraulic conductivity values range from 0.6 to 1.3% (Table 7-6 in the HA report). On the basis of this comparison, with other unconsolidated strata adjacent to the pit, the recharge rate applied to backfill areas looks anomalously high.*	A higher 5% infiltration rate has been applied generally consistent with experience for other accepted groundwater models for open cut mining operations in Qld (HydroSimulations, 2014), and is not considered anomalously high, noting that mine waste rock material is typically broken rock with lesser clay/fine components which might otherwise be found in Quaternary units deposited by fluvial processes. Consideration of Hawkins (1998) is referred to earlier in the report. Corresponding updates have been made to **Section 8.3.3**.

Table A2-6 (Continued)
Summary of AGE Consultants Stage 3 Independent Peer Review Findings [7 May 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
247	AGE [157]	*3.2.6. [Cont.] As summarised in Table 8-2 in the HA report evaporation extinction depths and maximum rates applied in backfilled areas have been assumed to be unchanged, relative to pre-mining rates. In effect this means that evaporation has been assumed to occur to depths of 8 m throughout the open cut area.*	As previously noted, where drawdown depths throughout the open cut mining area are in the order of +150 m and then backfilled, application of the linearly reducing rate of evapotranspiration is of little consequence. This is further confirmed by AGE in 3.2.9: *However, subsequent analysis of the raw model files provided suggests that this is not the case and that evaporation would only occur from backfilled areas once groundwater levels rise to within 8 m of the final post development ground level. As this is likely to only occur well after mining operations cease then modelled evaporation losses from the open cut area during mining are likely to be insignificant.*
248	AGE [158]	*All open cut areas are to be backfilled during mine closure, presumably to above the water table. Accordingly no simulation of long term water levels in residual mine voids have been undertaken.*	Comment noted. However, it should be noted that recovery of water levels in the long term in the backfill spoil has been undertaken.
249	AGE [159]	*3.2.7. Based on the reporting provided it is understood that model parameters relating to horizontal hydraulic conductivity, anisotropy, specific yield and specific storage only were calibrated. In particular, other than an adjustment to the initial infiltration rate for Quaternary alluvium (Qa and Qhe) from 1.3% to 1.5%, there is no mention of calibration of modelled recharge rates. Similarly it would appear that modelled conductance values assigned to river cells have also not been adjusted during the calibration.*	As confirmed in prior email correspondence calibration of K_H/%Infiltration (i.e. recharge) was (**Section 7.7.1**) and should be corrected. An additional parameter analysis has been completed as outlined in **Section 8.11.6** and three model sensitivity outputs presented in **Attachment 18**. Comparisons of outputs are relevantly made on **Graphs 8-6 and 8-7**. The river bed conductance was reduced and enhanced by a factor of 5 which would, assuming the bed area was unchanged, investigate an equivalent range from 0.05 m/day to 0.002 m/day. It is important to however note that streambed conductance is a function of K (hydraulic conductivity of the riverbed material), L (length of the stream reach), W (width of the river) and 1/M (thickness of the riverbed), which are all variables and inherently estimated in a model, but are only applicable to the RIV cells within the entire model domain. It is noted that AGE Consultants completed review of the numerical model build and calibration as part of Stage 2 for the current study.
250	AGE [160]	*3.2.7. [Cont.] No further information on the precise methodology adopted (PEST supports a range of different approaches) or on matters such as observation weighting which can significantly affect the success of the calibration are provided. Nevertheless, a low calibrated Scaled RMS (SRMS) statistic of 2.0% is reported for the transient calibration, which suggests that overall the model is able to replicate observed heads relatively well. The availability of calibration data in the Styx Coal Measures particularly in an around the proposed open cut area has been substantially improved compared to previous iterations of the project EIS.*	Comment noted. As demonstrated in **Section 7.7** and supported by the post calibration validation (**Section 7.8**) , the calibration performance is considered acceptable.
251	AGE [161]	*3.2.7. [Cont.] It is not clear from the legend on these figures whether negative values indicate under prediction or vice versa. The modelling team may also wish to consider whether contouring of this data and including contours in areas where the Styx coal measures are not actually present makes the issue appear visually worse and more pervasive than it actually is.*	The negative (under-predict) and positive (over-predict) values have been clarified in the supporting text. As shown on the figures, the contours labels range from 1 m to -4 m across the majority of the area of interest in the Cenozoic sediments. Extrapolated residuals in the deeper units or at substantial distance from the CQC Project are of course of lesser interest, but is presented transparently.

Table A2-6 (Continued)
Summary of AGE Consultants Stage 3 Independent Peer Review Findings [7 May 2020]

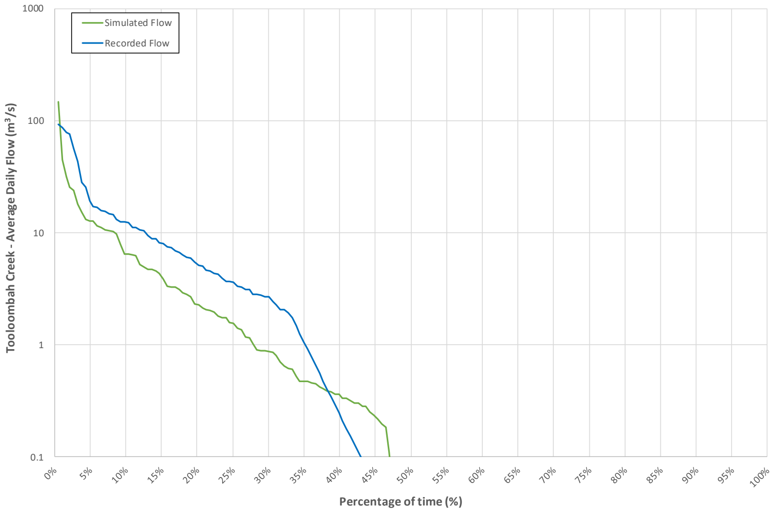
ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
252	AGE [162]	*3.2.7. [Cont.] Furthermore information on the location and elevation of semi-permanent pools along Tooloombah and Deep creeks which could also have been used has also been excluded from the calibration. In the reviewer's opinion, the inclusion of these additional targets would likely have improved the overall calibration and reduced predictive uncertainty by reducing the potential for non-uniqueness in the solution. However, confidence in the reliability of the model calibration could also be improved without re-calibration by using this same data to validate aspects of the model, as described in Section 3.6.3.*	As outlined in **Section 7.8.1**, post model calibration of pool survey levels are now presented, based on survey elevations by CCS Surveys Pty Ltd at five (5) locations in May 2020. At a zoomed-in scale, **Graph 7-7** shows for: • Tooloombah Creek: the applied RIV cell stage (+1 m) is a good fit, whereas the zero stage elevation applied (recommended by the peer review as a model sensitivity run [**Section 8.11.6**]) is lower; and • Deep Creek: the approximate 2 m differential is not unexpected at the higher topographic locations, recognising that the groundwater model groundwater level prediction is at end of calibration period corresponding with extended dry period (Sept-Oct 2019) (and dry observation records), versus surveyed pool levels recorded in May 2020, post the January-February 2020 rainfall events and is consistent with the applied RIV cell stage (0 m). The survey levels have also been used to tie the gauging station streamflow records since installation to mAHD and are shown on **Graphs 5-1 and 5-2** for relative comparison with groundwater levels recorded at WMP05 (Qa) and WMP04 (Qpa). As determined by WRM Water & Environment (2020), the flow duration curves (FDC) for Tooloombah Creek and Deep Creek suggest very low to no flow occurs for more than 80% of the time (**Sections 3.3.3 and 3.3.4**), which were at odds with CDM Smith analysis. Periodic sampling of surface water monitoring sites since mid-2019 also recorded dry reaches. Of interest however is WRM's updated curve for the period of flow record for Tooloombah Creek gauging station which notably is cut-off at 0.1 m^3/s (not 0.0001m^3/s) as provided in the FDC: 

Table A2-6 (Continued)

Summary of AGE Consultants Stage 3 Independent Peer Review Findings [7 May 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
253	AGE [163]	*3.2.7. [Cont] In some cases reported mean values for layers are at either the adopted upper and lower bounds suggesting that the ranges adopted for calibration may have been too restrictive. The sensitivity of model predictions to this restriction should ideally be assessed during the uncertainty analysis by the adoption of wider ranges.*	Double the Sy range was explored for Kx, Kx/Kz and KxInfil parameters. As outlined in **Attachment 11**, a log standard deviation of 0.5 was applied for others such that 95% of randomly sampled values should lie within one order of magnitude (two standard deviations) either side of the calibrated parameter values. Absolute minimum and maximum parameters are not considered relevant for such statistical analysis, particularly for such uncertainty analysis and therefore are not presented. For the purposes of risk-based assessments, application of wider ranges as suggested are then compounding and of limited use.
254	AGE [164]	*3.2.8. Modelled Water Balance* *The elevated losses close to the northern boundary related to evaporation being applied to cells adjacent to the constant head boundary elevation of 3 mAHD. To meet this evaporation demand water is being pulled from the offshore area which explains the relatively large volume of inflow (19.1 ML/day) from constant head cells reported in the modelled water budget.*	As above, correct reference from 3 mAHD to 3.5 mAHD. A modelled sensitivity run was completed down to 2 mAHD, and also relevantly note that there is a localised topographic depression at the confluence of Granite Creek, Montrose Creek and the Styx River which is specifically discussed and shown on **Figure 4-10** (not the head is at 1 mAHD near the confluence). This adds further to AGE's conclusion that the evaporation demand water volumes are "…*unlikely to affect any of the key impact predictions*."
255	AGE [165]	*3.2.9. It should be stressed, however, that this plot is reported to be based on modelled drain flows only. Elsewhere the reporting suggests that evaporation may also be occurring from those parts of the open cut areas which have been backfilled. However, subsequent analysis of the raw model files provided suggests that this is not the case and that evaporation would only occur from backfilled areas once groundwater levels rise to within 8 m of the final post development ground level. As this is likely to only occur well after mining operations cease then modelled evaporation losses from the open cut area during mining are likely to be insignificant.*	Comment noted.
256	AGE [166]	*3.2.9. [Cont.] Maps showing predicted drawdown in most model layers at various times as well as maximum all-time drawdown contours are presented in Attachment 14 of the HA report. Of these maps the maximum all time drawdown information is considered to be the most critical and consideration should be given to including these maps on a separate page, perhaps also zooming in to the area where impacts are predicted. Currently these maps are presented in "a four maps to a page" format and are difficult to read at the scale presented.*	**Attachment 14** has been updated to present a zoom in plot of the maximum drawdown prediction.

Table A2-6 (Continued)
Summary of AGE Consultants Stage 3 Independent Peer Review Findings [7 May 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
257	AGE [166]	*3.2.9. [Cont.] This suggests that the majority of water entering the open pit is either being drawn from these two nearby creeks or would otherwise have discharged to them.*	This is a speculative suggestion based on the numbers being similar and is simply not the case. Note the additional parameter sensitivity for investigating pit inflows (**Section 8.11.6**). The largely unchanged predictions for annual mine inflow (**Attachment 18**) and peak inflow (**Graph 8-6**) demonstrate that direct inflows from Tooloombah Creek in the long term to the open cut pit is unlikely. This supports the concept of indirect (i.e. piston-like) groundwater movement effects, as the quantum of predicted inflows to the open cut drains still occurs from water stored in the immediately surrounding rocks, and is not drawn direct from the creeks. It is noted that the only differentials apparent are during the first two years of the CQC Project, when the open cut pit is nearest Tooloombah Creek, and are only 3% to 5% different for the CQC-LF3 model.
258	AGE [167]	*3.2.9 [Cont.] As discussed previously in Section 3.2.6 the substantially higher recharge rate assigned to these waste rock emplacement areas than anywhere else in the model looks somewhat anomalous and could lead to suggestions from regulators and other reviewers that the potential positive impacts of this aspect of the project have been over-estimated.*	The applied rate (5%) is considered reasonable and is generally consistent with experience for other accepted groundwater models for open cut mining operations in Qld (HydroSimulations, 2014), noting that mine waste rock material is typically broken rock with lesser clay/fine components which might otherwise be found in Quaternary units deposited by fluvial processes. The report does not suggest this to be "potential positive impact", it simply presents the model results which would conceptually be expected to occur with an elevated post-mining landform (up to 75 m above the pre-mine surface). The conclusion drawn is groundwater levels substantially recover over many decades by enhanced rainfall recharge/infiltration at the surface across the backfill spoil and emplacement areas. The recovery was run for 500 years (in line with CDM Smith's previous modelling), but shows substantial recovery occurs in ~100 years. Note also this must be contextualised by the change in the post-mining surface water catchments which is predicted by WRM Water & Environment to be in the order of an additional **+2.22 km^2** of runoff reporting post-mining to the same reach (**Table 9-1**). This is specifically why the Mineral Waste Management Plan is of relevance to groundwater matters for longer-term water management (i.e. identifies the potential for discharge). However, the predicted quantum of change (**Graph 8-3**) is considered negligible.
259	AGE [168]	*3.2.10. In keeping with the rest of the technical report a wealth of detail on the results of this analysis are presented in Section 8.11.1 and Attachment 16 of the HA report. Some of the implications of this analysis are also discussed as required by the IESC.*	Noted.
260	AGE [169]	*3.2.10. [Cont.] However, it should be noted that this analysis has been limited to the same parameters which were varied during the calibration (i.e. horizontal hydraulic conductivity, anisotropy, specific yield and specific storage only, Section 3.2.7). Accordingly the sensitivity of observations to a number of other model parameters which include river bed conductance do not appear to have been assessed.*	An additional parameter analysis has been completed as outlined in **Section 8.11.6** and three model sensitivity outputs presented in **Attachment 18**. Comparisons of outputs are relevantly made on **Graphs 8-6 and 8-7**. The river bed conductance was reduced and enhanced by a factor of 5 which would, assuming the bed area was unchanged, investigate an equivalent range from 0.05 m/day to 0.002 m/day. It is important to however note that streambed conductance is a function of K (hydraulic conductivity of the riverbed material), L (length of the stream reach), W (width of the river) and 1/M (thickness of the riverbed), which are all variables and inherently estimated in a model, but are only applicable to the RIV cells within the entire model domain.
261	AGE [170]	*3.2.11. A number of other model parameters, including in particular river bed conductance, which may affect key model predictions have therefore not been assessed.*	As above.

Table A2-6 (Continued)
Summary of AGE Consultants Stage 3 Independent Peer Review Findings [7 May 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
262	AGE [171]	*3.2.11. [Cont.] Reference to Tables 1 to 5 in Attachment 11 of the HA report suggests that only relatively narrow ranges of Kx, anisotropy and storage have been assessed up to around an order of magnitude around the specified mean values. For some parameters, including specific yield, this may be appropriate but for most others we would expect a larger range of values to be tested. However, it is not clear from the reporting provided what ranges of values have been explored. Graphical illustrations of the distribution of prior and posterior values generated or a table summarising minimum and maximum parameters from the 600 generated realisations should be provided to confirm.* *Furthermore a relatively narrow calibration constraint has also been adopted, whereby any run where the SRMS exceeds 3% has been excluded from the analysis on the basis that it is inconsistent with the observations. It is recognised that a SRMS value of 3% represents a calibration that is statistically 50% worse than the fully calibrated model, which achieved a SRMS of 2%. However, a SRMS of up to 10% is often considered acceptable in many modelling studies and hence a model achieving a SRMS of 3% would still generally be considered to be very well calibrated.*	Double the Sy range was explored for Kx, Kx/Kz and KxInfil parameters. As outlined in **Attachment 11**, a log standard deviation of 0.5 was applied for others such that 95% of randomly sampled values should lie within one order of magnitude (two standard deviations) either side of the calibrated parameter values. Absolute minimum and maximum parameters are not considered relevant for such statistical analysis, particularly for such uncertainty analysis and therefore are not presented. For the purposes of risk-based assessments, application of wider ranges as suggested are then compounding and of limited use. For the Surat study, *a threshold of 10%* above the base calibrated model* (<u>not SRMS of 10%</u>) was used to define a "acceptable level of misfit", under which the models were deemed to be "calibrated". Thus, the improved CQC groundwater model has used a more conservative threshold of 50% (i.e. 10 x greater than the Surat study). *Applied to the PEST objective function, which is a sum of square error and if converted to an equivalent SRMS threshold, would be equal to 1.1 * SSE = sqrt (1.1) * RMS (i.e. about ~4.9%).
263	AGE [172]	*3.2.12. A further scenario based sensitivity analysis run is therefore recommended in Section 3.6.2 as being the simplest way of confirming the sensitivity (or otherwise) of key model predictions to this parameter.*	See **Flowchart A2-1**, **Section 8.11.6** and **Attachment 18**. The 8 m evapotranspiration extinction depth was applied only where moderate and high potential GDEs had been mapped, and 3 m everywhere else within the model domain (**Figure 8-10**). As shown in the key model outputs (**Attachment 18**), the maximum predicted drawdown extents are largely the same, and the peak mine inflow and baseflow/leakage change predictions are slightly higher than the CQC-LF3 results, but all well within probability of exceedance of 50% (as likely as not) or approaching very likely (90%) (**Graphs 8-6 and 8-7**).
264	AGE [173]	*3.3. No significant discrepancies between the model reporting and model files were identified.*	Noted.
265	AGE [174]	*3.4. In general the report is a very long and challenging read. Excluding appendices and other attachments the main report is currently around 270 pages. The length of the report may well test the patience of the IESC panel and the secretariat and DoEE staff who support them, especially as they continue to emphasise the need for a high level of reporting clarity in their various guidelines.*	The reporting has been rationalised where considered relevant, however reference is made, by way of example, to other groundwater assessments (e.g. AGE Consultants, main report **320pp**). When comparing the assessment chronology to other projects, the use of superficial "page count" metrics are of no relevance. Orange Environmental is preparing the **stand-alone Version 3 SEIS MNES sections** which will contain sufficient information to be read alone by the IESC / DAWE with reference to the technical groundwater report and other relevant technical data and supplementary reports. Therefore, such speculative suggestions that the patience of IESC panel, secretariat and DAWE staff would be tested is unnecessary.

Table A2-6 (Continued)
Summary of AGE Consultants Stage 3 Independent Peer Review Findings [7 May 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
266	AGE [175]	*3.4. [Cont.] Consideration should be given to including the detailed description of the numerical modelling work and long lists of monitoring points and other data in appendices.*	We note this is an AGE reporting format preference. The report structure is however fit for purpose to allow presentation in a systematic and chronological manner (data-conceptualisation-model build-calibration-model run-uncertainty analysis-assessment and monitoring-management) but to also address the regulator submissions and past IESC advice. The reporting is aimed not only at the IESC and DAWE, but also the DES (for the purposes of developing draft EA conditions – which requires the lists of monitoring points as per the model conditions), and the data presented is specifically tailored to support the model conceptualisation in response to the regulator submissions (i.e. has already been rationalised).
267	AGE [176]	*3.4. [Cont.] Specific items …* • *section 5 in particular includes some long lists of data (e.g. in Section 5.6.7) which could be summarised in much shorter tables and/or removed to an appendix;*	No change. The section is specifically presented in the expanded/listed form for each hydrogeological unit (in this case the Back Creek Group which was criticised in previous government review – see **Attachment 1**) to demonstrate the quantum of testwork which appeared to have been overlooked in previous regulatory review/submissions because it was summarised in shortened tables and appendix by CDM Smith (2018). This was reiterated during the DES meetings to point out the substantial site-specific testwork that has been completed for the different units (See Slide 6 in the November meeting slides [*73 estimations across 31 locations*]. This is again important to contextualise for the uncertainty analysis and parameterisation justification.
268	AGE [177]	• *several key maps including Figures 5-3, 5-4 and 7-1 are presented as simple images inserted into the document at a scale which makes them hard to read and often without legends, scales or north arrows etc;*	Figures have now been included (in a figure template with scales, legends and north symbol) with enhanced resolution [large file size]) as we had been awaiting the draft SEIS Version 3 figures for inclusion from OE (i.e. to avoid unnecessary duplication).
269	AGE [178]	• *section 7.5.3 includes a long justification of why the MODFLOW stream package has not been used. It is not clear why most of the information provided is relevant, we suggest that this discussion could be deleted; and*	The reasoning for not applying MODFLOW stream cells is included in direct response to AGE Consultants earlier peer review comment that "*consideration should be given to using a more complex boundary condition (e.g. MODFLOW streams)."* That is, the conclusion made is the stream package is considered unnecessary over-parameterisation, and the application of RIV cells is justified.
270	AGE [179]	• *the text relating to River Bed Conductance at the end of Section 7.4.4 appears to be largely a repeat of similar text at the end of 7.5.3.*	Note River Bed Conductance is not described in **Section 7.4.4**. **Section 7.5.3** relates to watercourses and drainages and therefore outlines how the parameter has been applied in the model (applied widths). It is important to note that streambed conductance is a function of K (hydraulic conductivity of the riverbed material), L (length of the stream reach), W (width of the river) and 1/M (thickness of the riverbed), which are all variables and inherently estimated. **Section 7.5.4** relates to rainfall recharge and flooding which relevantly notes that river bed conductance values can be factored (if necessary) during calibration (to better reflect flood recharge), but as described elsewhere the model calibration cut-off was Sept-Oct 2019 (prior to flow records). Subsequently, validation of applied stage levels is included (**Section 7.8.1**), model sensitivity scenario has been run for river bed conductance (**Section 8.11.6**) and future opportunities recognised for flood recharge events (**Section 8.12.2**).

Table A2-6 (Continued)
Summary of AGE Consultants Stage 3 Independent Peer Review Findings [7 May 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
271	AGE [180]	*3.5.1. Given the sensitivity of some of the potential impact receptors of the project which include high priority wetlands and the Great Barrier Reef (i.e. a high overall risk context) then the IESC may argue that development of more integrated surface water and groundwater models should have been undertaken.*	It is noted AGE states "*If anything, the model domain is perhaps more extensive than strictly necessary*". The Great Barrier Reef Marine National Park Zone MNP-21-1146 (Broad Sound area including the Bedwell Group, Wild Duck and Bamborough Island) defined under the *Commonwealth Great Barrier Reef Marine Park Act 1975* is located approximately 40 km to the north-east of the CQC Project, and is beyond the numerical groundwater model domain. **Section 11.1** outlines the relevant distances to wetlands, Broad Sound FHA, etc., and allows comparison to predicted drawdown extents toward the north. **Figure 8-4** shows the distance to the Styx River mouth (some 25 km) and model predictions were shown to be insensitive to the tidal boundary condition applied at such distance. **Sections 3.4.5, 6.3.2 and 7.5.6** specifically describes how historic coal mining occurred across several decades downstream of the CQC Project and was included in the numerical groundwater model for the purposes of cumulative assessment (**Section 8.10**). This Report therefore has considered and assesses potential drawdown and storage change at the boundary of FHA-047 [and therefore approximately the boundary of DIWA Broad Sound] (at approximately 8 km), which can then also be applied/inferred for the General Use Zone, World Heritage Property and National Heritage Place. Note that CQCPL has commissioned a separate Surface Water – Groundwater Integrated Model developed by Eco Logical Australia Pty Ltd (2020d), which is referenced in the report however has not yet been received.
272	AGE [181]	*3.5.2. As discussed in Section 3.2.7 due partly to data limitations calibration has been undertaken to observed groundwater levels only and is likely therefore to be more prone to non-uniqueness than if other types of calibration data were available. The sensitivity of key model predictions to non-uniqueness has been assessed through the development of more than 600 alternative parameter sets as part of the uncertainty analysis (Section 3.2.11). However, not all parameters were included in this analysis and the parameter ranges used were arguably too narrow.*	An additional parameter analysis has been completed as outlined in **Section 8.11.6** and three model sensitivity outputs presented in **Attachment 18**. Comparisons of outputs are relevantly made on **Graphs 8-6 and 8-7**. Double the Sy range was explored for Kx, Kx/Kz and KxInfil parameters. As outlined in **Attachment 11**, a log standard deviation of 0.5 was applied for others such that 95% of randomly sampled values should lie within one order of magnitude (two standard deviations) either side of the calibrated parameter values. The river bed conductance was reduced and enhanced by a factor of 5 which would, assuming the bed area was unchanged, investigate an equivalent range from 0.05 m/day to 0.002 m/day.
273	AGE [182]	*3.5.3. As discussed previously in Section 3.2.7 and recommended in Section 3.6.3 confidence in the reliability of the model calibration could have been achieved by comparison with recently acquired flow and pool level data for Tooloombah and Deep creeks with model outputs.*	As outlined in **Section 7.8.1**, post model calibration of pool survey levels are now presented, based on survey elevations by CCS Surveys Pty Ltd at five (5) locations in May 2020. At a zoomed-in scale, **Graph 7-7** shows for: • Tooloombah Creek: the applied RIV cell stage (+1 m) is a good fit, whereas the zero stage elevation applied (recommended by the peer review as a model sensitivity run [**Section 8.11.6**]) is lower; and • Deep Creek: the approximate 2 m differential is not unexpected at the higher topographic locations, recognising that the groundwater model groundwater level prediction is at end of calibration period corresponding with extended dry period (Sept-Oct 2019) (and dry observation records), versus surveyed pool levels recorded in May 2020, post the January-February 2020 rainfall events and is consistent with the applied RIV cell stage (0 m). The survey levels have also been used to tie the gauging station streamflow records since installation to mAHD and are shown on **Graphs 5-1 and 5-2** for relative comparison with groundwater levels recorded at WMP05 (Qa) and WMP04 (Qpa).

Table A2-6 (Continued)
Summary of AGE Consultants Stage 3 Independent Peer Review Findings [7 May 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
274	AGE [183]	*3.5.4. Almost 1000 runs of the model were completed as part of the uncertainty analysis, of which only 5 runs were reported to have been affected by non-convergence suggesting that the model is relatively stable. However, as mentioned above against Item 5 not all parameters were included in this analysis and the parameter ranges used were arguably too narrow.*	Comment noted. For the Surat study, *a threshold of 10%* above the base calibrated model* (not SRMS of 10%) was used to define a “acceptable level of misfit”, under which the models were deemed to be “calibrated”. Thus, the improved CQC groundwater model has used a more conservative threshold of 50% (i.e. 10 x greater than the Surat study). Double the Sy range was explored for Kx, Kx/Kz and KxInfil parameters. As outlined in **Attachment 11**, a log standard deviation of 0.5 was applied others such that 95% of randomly sampled values should lie within one order of magnitude (two standard deviations) either side of the calibrated parameter values. If SRMS up to 10% was applied the UA is not calibration-constrained and all runs would be accepted, therefore is not considered further. *Applied to the PEST objective function, which is a sum of square error and if converted to an equivalent SRMS threshold, would be equal to 1.1 * SSE = sqrt (1.1) * RMS (i.e. about ~4.9%). An additional parameter analysis has been completed as outlined in **Section 8.11.6** and three model sensitivity outputs presented in **Attachment 18**. Comparisons of outputs are relevantly made on **Graphs 8-6 and 8-7**.
275	AGE [184]	*3.5.5. Appropriate identifiability and uncertainty analyses have been completed, although as discussed above some potentially key parameters were excluded.*	Comment noted. An additional parameter analysis has been completed as outlined in **Section 8.11.6** and three model sensitivity outputs presented in **Attachment 18**. Comparisons of outputs are relevantly made on **Graphs 8-6 and 8-7**.
276	AGE [185]	*3.5.6. As discussed previously (Section 3.4) in the peer reviewers opinion the current report is longer than its needs be and this affects the clarity of the reporting. As far as possible data and technical detail should be incorporated as appendices to reduce the length of the main report to a more manageable length. Evidence of engagement with regulatory bodies (to address checklist item 1) should also be included.*	The reporting has been rationalised where possible, but as demonstrated in **Attachment 1**, also addresses many specific requirements of prior regulatory engagement. The reporting structure is standardised as outlined in **Section 1.3** and includes **18 Attachments.** Reference is made to other groundwater assessments prepared by the peer reviewer (e.g. AGE Consultants, main report **320pp**) which are also substantial in length. The document purpose is not only for IESC/DAWE but also for the DES and development of future draft EA conditions. As above, **Attachment 1** is included as direct evidence of prior engagement with regulatory bodies to date. Further, a copy of the briefing slides for the two meeting presentations made to DES is provided in **Attachment 17**.
277	AGE [186]	*3.6.1. A simple additional impact sensitivity run is therefore recommended whereby Tooloombah Creek is modelled using the same approach as other creeks in the area such that it cannot leak. Effectively this run would represent a test of an alternative conceptual model, in which leakage from Tooloombah Creek is assumed to be insignificant. Such an assumption is also consistent with the available data which suggests possible disconnection and highly ephemeral flows. Once run key predictive outputs in the form of predicted mine inflows, 2 m drawdown contours and predicted impacts should be compared to current predictions to assess the significance (or otherwise) of the current conceptual model and river boundary assumption.*	Refer to **Section 8.11.6**. For the purposes of comparison with the results presented for the CQC-LF3 model which applied a stage depth of 1 m along Tooloombah Creek Reach 2 (**Figure 7-4**), all RIV cells along the same reach were changed to a 0 m effective depth. As shown in the key model outputs (**Attachment 18**), in the absence of a stage boundary condition in Tooloombah Creek Reach 2, the maximum predicted drawdown extents conservatively propagate to the north-west, generally along the strike of the coal measures. Changes in key metrics demonstrate the peak mine inflow predictions are substantially the same, and peak baseflow/leakage change predictions along Tooloombah Creek is less, and by comparison to the 99.7% confidence intervals of probability of exceedance is greater than very likely (>90%) (**Graph 8-6 and 8-7**). It is also noted in **Section 7.8.1** (**Graph 7-7**) the surveyed pool levels along Tooloombah Creek in May 2020 (albeit two data points), provides a better fit with a stage depth of 1 m applied.

Table A2-6 (Continued)

Summary of AGE Consultants Stage 3 Independent Peer Review Findings [7 May 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
278	AGE [187]	*3.6.2. As described in Section 3.2.3.3 we are unable to support the use of 8 m maximum rooting depths across the majority of the area given that land use in the area is described as being dominated by livestock grazing and has been cleared. It is possible, however, that model predictions are not sensitive to this parameter and hence an additional impact sensitivity run is recommended in the first instance. Extinction depths in this run should be based on land use mapping rather than geology. Once run, key predictive outputs in the form of predicted mine inflows, 2 m drawdown contours and predicted impacts should be compared to current predictions to assess the significance (or otherwise) of the current conceptual model and evaporation boundary assumption.*	Refer to **Section 8.11.6**. Despite the clear qualitative justification presented in **Section 8.11.4** to apply the extinction depth across the Cenozoic sediments, primarily on the basis that the depth to groundwater table in most areas in the vicinity of the CQC Project are beyond 10 m (which was also consistent with the depth to groundwater maps presented on Figure 10-96 in CDM Smith [2018b] across the Cenozoic sediments), AGE Consultants requested that the numerical model be re-run to quantify the changes. Therefore, the 8 m evapotranspiration extinction depth was applied only where moderate and high potential GDEs had been mapped, and 3 m everywhere else within the model domain (**Figure 8-10**). As shown in the key model outputs (**Attachment 18**), the maximum predicted drawdown extents are largely the same, and the peak mine inflow and baseflow/leakage change predictions are slightly higher than the CQC-LF3 results, but all well within probability of exceedance of 50% (as likely as not) or approaching very likely (90%) (**Graph 8-6 and 8-7**).
279	AGE [188]	*3.6.3. As discussed in Section 3.2.7 a number of data sets including flow data and levels in semi-permanent pools for Tooloombah and Deep Creek and observed vertical head differences at nested monitoring sites have not currently been used for model calibration. This data should instead be compared with model predictions ideally confirming that the model is able to replicate observed baseflows, head differences and pool levels at these locations. Where a reasonable match can be achieved, despite the observations being excluded from the calibration, then this would go some way to validating the current model and the predictions made.* *… However, no comparisons of modelled and observed flows at the recently installed flow gauging stations or groundwater levels at the location of the semi-permanent pools on Tooloombah and Deep creeks are presented. Instead Section 7.8 of the HA report suggests that model validation cannot be undertaken at this stage.*	As previously noted, the model could not be calibrated with flow data as the cut-off date was Sept-Oct 2019. **Section 7.7.1** states: Despite the installation of stream flow gauges, there were no flow events recorded at the time of cut-off for model calibration datasets which was a known/planned limitation, recognising that the numerical groundwater model would be subject to robust uncertainty analysis (**Sections 8.11 and 8.12**) and future review and validation (**Section 10.9**). Thus, no reliable stream flow, baseflow or seep/spring flow data was available to calibrate at the time. Similarly, as the CQC Project is yet to commence, model calibration <u>to mine inflow or dewatering datasets</u> is unable to be carried out. **Section 7.8** has been clarified to state that model validation <u>of predicted changes (i.e. mine inflows)</u> cannot be undertaken at this stage. However, as outlined in **Section 7.8.1**, post model calibration of pool survey levels are now presented, based on survey elevations by CCS Surveys Pty Ltd at five (5) locations in May 2020. At a zoomed-in scale, **Graph 7-7** shows for: • Tooloombah Creek: the applied RIV cell stage (+1 m) is a good fit, whereas the zero stage elevation applied (recommended by the peer review as a model sensitivity run [**Section 8.11.6**]) is lower; and • Deep Creek: the approximate 2 m differential is not unexpected at the higher topographic locations, recognising that the groundwater model groundwater level prediction is at end of calibration period corresponding with extended dry period (Sept-Oct 2019) (and dry observation records), versus surveyed pool levels recorded in May 2020, post the January-February 2020 rainfall events and is consistent with the applied RIV cell stage (0 m). The survey levels have also been used to tie the gauging station streamflow records since installation to mAHD and are shown on **Graphs 5-1 and 5-2** for relative comparison with groundwater levels recorded at WMP05 (Qa) and WMP04 (Qpa).

Table A2-6 (Continued)
Summary of AGE Consultants Stage 3 Independent Peer Review Findings [7 May 2020]

ID	REVIEW [REF]	INDEPENDENT REVIEW COMMENT EXCERPT / SUMMARY	RESPONSE
280	AGE [189]	*3.6.4. … the exclusion of this parameter from the uncertainty analysis, as well the calibration and the identifiability analysis, is considered to be a significant flaw in the current study. We would therefore suggest that the uncertainty analysis be repeated including river bed conductance and other parameters.*	An additional parameter analysis has been completed as outlined in **Section 8.11.6** and three model sensitivity outputs presented in **Attachment 18**. Comparisons of outputs are relevantly made on **Graphs 8-6 and 8-7**. The river bed conductance was reduced and enhanced by a factor of 5 which would, assuming the bed area was unchanged, investigate an equivalent range from 0.05 m/day to 0.002 m/day. It is important to however note that streambed conductance is a function of K (hydraulic conductivity of the riverbed material), L (length of the stream reach), W (width of the river) and 1/M (thickness of the riverbed), which are all variables and inherently estimated in a model, but are only applicable to the RIV cells within the entire model domain. It is noted that AGE Consultants completed review of the numerical model build and calibration as part of Stage 2 for the current study.
281	AGE [190]	*3.6.4. [Cont.] Consideration should also be given to widening the range of hydraulic conductivity values assessed during the analysis and also retaining model runs with higher SRMS values (see Section 3.2.11).*	For the Surat study, *a threshold of 10%* above the base calibrated model* (not SRMS of 10%) was used to define a “acceptable level of misfit”, under which the models were deemed to be “calibrated”. Thus, the improved CQC groundwater model has used a more conservative threshold of 50% (i.e. 10 x greater than the Surat study). Double the Sy range was explored for Kx, Kx/Kz and KxInfil parameters. As outlined in **Attachment 11**, a log standard deviation of 0.5 was applied others such that 95% of randomly sampled values should lie within one order of magnitude (two standard deviations) either side of the calibrated parameter values. If SRMS up to 10% was applied the UA is not calibration-constrained and all runs would be accepted, therefore is not considered further. *Applied to the PEST objective function, which is a sum of square error and if converted to an equivalent SRMS threshold, would be equal to 1.1 * SSE = sqrt (1.1) * RMS (i.e. about ~4.9%).
282	AGE [191]	*3.6.4. [Cont.] It would also assist the peer review process if a simple summary table could be added to the reporting confirming which model parameters were adjusted during the calibration and were assessed as part of the identifiability and uncertainty analysis and those that were not.*	Please see **Flowchart A2-1**.
283	AGE [192]	*3.6.4. [Cont.] For instance the final paragraph in Section 7.5.4 on page 154 of the HA report suggests that river bed conductance may have been varied during calibration and assessed as part of the uncertainty analysis. However, subsequent direct enquiries with the model developers have confirmed that this model parameter was not varied in either modelling stage.*	**Section 7.5.4** relates to flood recharge. The statement made was specifically in relation to flood recharge to explain that when modelling it can be factored (if necessary) during calibration and uncertainty analysis (for sensitivity scenarios). **Section 8.12.2** relates to opportunities for future modelling exercises.

Flowchart A2-1
CQC-LF3 Groundwater Model Parameter Testing Summary

Groundwater Model			Key Metrics Mine Inflows	 Spatial Drawdown	 Changes to Baseflow / Leakage		
CQC-LF3 Groundwater Model [February 2020] Predictions and Assessment			✓	✓	✓		
Parameter Analysis and Testing to Build Confidence in Model Predictions							
Calibration and Identifiability#*^~	K_H/%Infiltration [*surrogate recharge*]	✓	N/A – Pre-Mine Only				
	$K_{HORIZONTAL}$ [*hydraulic conductivity*]	✓					
	$K_{HORIZONTAL}$/$K_{VERTICAL}$ [*anisotropy*]	✓					
	S_s [*storativity*]	✓					
	S_y [*specific yield*]	✓					
[I] Sensitivity Analysis – Tidal Boundary Condition (& Sea Level Rise)							
Fixed Head at Styx River Mouth	Change -1.5 m		-	✓	-	Negligible differences	**Outcome:** Maintain CQC-LF3.
Fixed Head at Styx River Mouth	Change +1.0 m		-	✓	-		
[II] Sensitivity Analysis – Rainfall Recharge Totals							
Climate Change – Reduced Recharge (*surrogate EVT increase in balance*)	Change -20%		✓	-	-	Average predicted take/inflows reduced on average by 15.7%. SRMS Error Diverges.	**Outcome:** Well within **[IV]** by comparison, Maintain CQC-LF3.
Climate Change – Increased Recharge (*surrogate EVT decrease in balance*)	Change +20%		✓	-	-	Average predicted take/inflows increased on average by 16.9%. SRMS Error Diverges.	**Outcome:** Well within **[IV]** by comparison, Maintain CQC-LF3.
Sea Level Rise Projections	Change +0.8 m		-	✓	-	Within range of [I] above.	**Outcome:** Maintain CQC-LF3.
[III] Maximum ET Rate and Extinction Depths {**Refer [X]**}							
Reduce Maximum ET Rate Refine ET Extinction Depth (Relationship)	*Recognised CDM Smith applied high evaporation value and therefore applied lower maximum ET rate. Extinction depths based on vegetation and geology, but recognising depth to gw table was >10mbgl in Cenozoic sediments across ML 80187, running a sensitivity applying a lesser value again with refinements was considered unnecessary. [**Refer X**]*						**Outcome:** Maintain CQC-LF3.
[IV] Hydraulic Conductivity Zones (and Surrogate Recharge)							
$K_{HORIZONTAL}$/%Infiltration [*recharge*]	LND with 0.5 SD		✓	✓	✓	**Refer Table 8-8** with corresponding probabilities [*Note the CQC-LF3 SRMS Error is the lowest i.e. best fit*]	**Outcome:** Maintain CQC-LF3, *Recognise ranges for risk-based assessments.*
$K_{HORIZONTAL}$ [*hydraulic conductivity*]	LND with 0.5 SD		✓	✓	✓		
$K_{HORIZONTAL}$/$K_{VERTICAL}$ [*anisotropy*]	Truncated LND with 0.5 SD & Min = 1		✓	✓	✓		
[V] Geological Structure (Fault) Zone of Hydraulic Conductivity							
$K_{VERTICAL}$ [*enhanced*]	Change Vertical Factor x 10 in mapped structure zones		-	✓	-	Very localised and negligible changes	**Outcome:** Maintain CQC-LF3.
$K_{VERTICAL}$ [*reduced*]	Reduced Vertical Factor in mapped structure zones		*Given the evidence of boundary effects already at the Styx Coal Measures and Permian Measures interface based on the LF3 case, and very localised changes based on the increased $K_{VERTICAL}$ factor a reduced vertical hydraulic conductivity scenario was not considered any further.*				**Outcome:** Maintain CQC-LF3.
[VI] Depth Dependence (Depth Function) in Coal Seams							
$K_{HORIZONTAL}$	Enforce in initial values and min/max parameter value bounds		*Whilst the calibration process did not enforce depth-dependence (except in initial values and min/max parameter value bounds) **[IV]** explored varied coal seam permeability values. Therefore, additional scenarios (i.e. without depth dependence) were not considered necessary.*				**Outcome:** Maintain CQC-LF3.
[VII] Specific Storage and Specific Yield							
S_s [*storativity*]	LND with 0.5 SD		✓	✓	✓	As above, **Refer Table 8-8** with corresponding probabilities	**Outcome:** Maintain CQC-LF3, *Recognise ranges for risk-based assessments (and offsets)+.*
S_y [*specific yield*]	LND with 0.25 SD		✓	✓	✓		
[VIII] Spoil Properties in Backfilled Voids – Apply TVM Properties							
$K_{HORIZONTAL}$ [*hydraulic conductivity*]	Increase to 1 m/day		*Applying host properties only (by CDM Smith) was criticised in previous peer review therefore sensitivity with host only was discounted. Enhanced recharge could have some effect on recovery timeframes which are predicted to be in the order of decades either way.*				**Outcome:** Maintain CQC-LF3.
$K_{HORIZONTAL}$/$K_{VERTICAL}$ [*anisotropy*]	Increase to 1						
S_s [*storativity*]	Increase to 1.3 x 10^{-5} [1/m]						
S_y [*specific yield*]	Increase to 0.2						
$K_{HORIZONTAL}$/%Infiltration [*recharge*]	Increase to 5%						
[IX] Predictive Sensitivity for Increased Landholder Pumping							
Drain Cells at Private Landholder Bores	*Based on the results of the numerical groundwater model outputs, review of the BH20-BH01X-BH16 monitoring, and consideration that use in the vicinity of the CQC Project is limited due to generally poor quality beyond the watercourses, a specific sensitivity scenario was not undertaken as it was unlikely to be of any consequence when considering all the other model parameterisation investigated.*						**Outcome:** Maintain CQC-LF3.
Additional Parameter Analysis and Testing to Build Further Confidence in Model Predictions (Stage 3 Peer Review)							
[X] Sensitivity Analysis – ET Extinction Depth							
Reduce ET Extinction Depth	Apply 8 m depth only where moderate and high potential GDEs are mapped, 3 m elsewhere.		✓	✓	✓	Negligible differences in drawdown extents, mine inflow predictions slightly less, little to no consequence.	**Outcome:** Well within **[IV]** by comparison, Maintain CQC-LF3.
[XI] Sensitivity Analysis – Tooloombah Creek Boundary Condition							
Remove Tooloombah Creek Boundary Condition	Change all RIV cells along Tooloombah Creek Reach 2 to a 0m effective depth (stage = river bottom elevation)		✓	✓	✓	Predictions extend further north-west as expected, consistent with **[IV]**, negligible change in mine inflow.	**Outcome:** Well within **[IV]** by comparison, Maintain CQC-LF3.
[XII] Sensitivity Analysis – River Bed Conductance							
Reduce River Bed Conductance	Apply reduced and enhanced river bed conductance factor to demonstrate mine inflow rates remain unchanged (minimal direct take)		✓	✓	✓	Reduced factor scenario results equivalent to **[XI]** in terms of drawdown extent, but importantly both scenario results reinforce the conclusion that predicted take from the streams to the open cut mine drains are minimal.	**Outcome:** Maintain CQC-LF3, monitor and validate model in future.

Blue Cells: Quantitative UA Results presented in Table 8-8; # Rainfall recharge applied based on %infiltration (varied spatially) of monthly averages; * EVT maximum rates and extinction depths varied spatially across the model domain.

^ River bed conductance value held constant at 0.01 m/day in calibration recognising the parameter could be considered during future groundwater model validation processes (as streamflow datasets are recorded since installation of the gauging stations on Tooloombah Creek and Deep Creek).

Subsequent model sensitivity run completed as required by peer review to demonstrate of negligible consequence when considering key metrics. ~ Boundary Condition (Stage = +1m) applied to Reaches 1 & 2 on Tooloombah Creek and Styx River. 0 m stage elsewhere.

Spot survey elevation (May 2020) comparison demonstrates a good match at two points on Tooloombah Creek Reach 2. Subsequent model sensitivity run completed as required by peer review to investigate prediction changes when considering key metrics.

LND = Lognormal Distribution; SD = standard deviation.

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Memorandum

Project number G2001
To Mr Nui Harris
Company Waratah Coal Pty Ltd
From Keith Phillipson/Andrew Durick, AGE Consultants Pty Ltd
Date 16 July 2020
RE **Central Queensland Coal groundwater model peer review – Stage 4**

1 Introduction and scope

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) were commissioned by Waratah Coal Pty Ltd in November 2019 to a undertake peer review of the Central Queensland Coal (CQC) Project groundwater model being constructed by HydroAlgorithmics (HA) as part of an EIS for the project.

This memo summarises the findings of the final stage (Stage 4) of the peer review, the scope of which was defined in AGE's proposal (AGE letter dated 12 November 2019) and comprised the review of final report sections and model files relating to the model build, calibration, numerical model predictions and uncertainty analysis. The Stage 4 review predominantly comprised a review of an updated version of the draft HA Numerical Groundwater Model and Groundwater Assessment Report dated May 2020.[1] This version of the report incorporated a number of changes and some additional modelling work resulting from previous stages of the review process.

The other ancillary documents not directly linked to the project that were used during this peer review were:

- Barnett, B, Townley, LR, Post, V, Evans, RE, Hunt, RJ, Peeters, L Richardson, S, Werner, AD, Knapton, A, & Boronkay, A (2012), *Australian groundwater modelling guidelines*. Waterlines report, National Water Commission, Canberra.
- Commonwealth of Australia (CoA), (2018), *Information guidelines for proponents preparing coal seam gas and large coal mining development proposals*, Commonwealth of Australia, May 2018.
- Middlemis H and Peeters LJM (2018), *Uncertainty Analysis – Guidance for groundwater modelling within a risk management framework*. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment and Energy, Commonwealth of Australia 2018.

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[1] HydroAlgorithmics, May 2020, Numerical groundwater model and groundwater assessment report – for the Central Queensland Coal Project Supplementary EIS – Responses to submissions, Version 4- Draft for final stage peer review.

2 Review findings

2.1 Review of the hydrogeological conceptualisation

The hydrogeological conceptualisation is presented in Section 6 of the HA report. This section includes a generally clear summary of the distribution and thickness of hydrostratigraphic units in the area and their hydraulic properties. There is an appropriate focus on surface water and groundwater interactions along the two creeks immediately adjacent to the proposed mining activity. The presented conceptual model is plausible and has identified the components responsible for bulk water movement into, though and out of the aquifers associated with the CQC project. There are some aspects of the conceptual hydrogeological model that could be improved, and these are discussed below.

2.1.1 Data Availability

Hydrological, hydrogeological and other data of relevance to the groundwater assessment are described in some detail in Section 5 of the HA report and data and other limitations which have the potential to affect model predictions are discussed in Section 8.12.

Substantial additional data has been collected since completion of the previous groundwater impact assessment (GIA) for the project[2] including the installation of:

- additional groundwater monitoring bores in both the Styx Creek Coal Measures and underlying Back Creek Group; and
- surface water flow and level monitoring stations installed on Tooloombah Creek and Deep Creek downstream of the proposed mine workings.

Water quality monitoring has also continued in these and other existing facilities and hence sub-surface salinity variations are also now better understood.

Remaining data limitations with the potential to affect the current conceptualisation, the majority of which are also recognised in the reporting include:

- the relatively short period of record currently available for the gauges on Tooloombah Creek and Deep Creek, the monitored period only includes a single recent flow event;
- flow gauging on Toolombah Creek upstream of the proposed mine workings; and
- a historic groundwater level data set comprising predominantly monthly manual dips, groundwater level loggers have currently only been installed in a small number of recent installations.

Additional data of this type would likely greatly assist with quantifying surface water – groundwater interactions in the vicinity of Tooloombah Creeks.

2.1.2 Hydrostratigraphic Units

The segregated hydrostratigraphic units (HSU) adopted in the conceptual model appear plausible and represent an improvement on the previous numerical model conceptualisation. In particular separate numerical model layers have been used to represent the three major coal seams (the Red Lower 2, Blue Lower 2 and Violet Lower 2) as well as overburden, interburden and underburden units.

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[2] CDM Smith, 2018d, Central Queensland Coal Project Supplementary Environmental Impact Statement: Appendix 6 – Groundwater Technical Report, Draft. 30 November 2018.

In total seven layers have been used to represent the Permian Styx Creek Coal Measures with a further four layers for the overlying Quaternary and Tertiary aged strata and three layers for the underlying Back Creek and Volcanic groups. The coal measure stratigraphy is shown in Figure 6-3 in the HA report. Consistent with peer review comments relating to previous iterations of the model, coal seam permeability has been assumed to reduce linearly with depth from 0.22 m/d at outcrop to a minimum of 0.002 m/d at around 250 m depth. Relationships between depth and coal seam permeability are well documented in the literature and most recent models (including OGIA, 2019[3]) developed for EIS and other purposes adopt similar depth dependent declines in hydraulic conductivity. Conceptually this is thought to be related to progressive compression and closure of the coal cleats as the weight of the overlying overburden increases.

2.1.3 Aquifer parameters

Substantial additional field hydraulic conductivity and storage data have been collected for the site since the previous EIS iteration, including continuous packer testing and laboratory analysis of core samples taken from the Styx Coal Measures to the base of the proposed open cut. Reference to Table 6-4 in the HA report indicates that relatively low initial anisotropy ratios (i.e. ratios between vertical and hydraulic conductivity) of between one and 25 were adopted for modelling purposes, based predominantly on results from core tests. In particular anisotropy ratios of two have been adopted for the interburden and underburden layers in the Styx Coal Measures. Given that the thickness and hence likely heterogeneity of these model layers is substantially greater than the scale of the core measurements used to derive the ratios, it is considered likely that these initial values represent under-estimates. However, the adoption of relatively low values is considered conservative, since it reflects modelled formation scale vertical hydraulic conductivity values which are likely to be higher than a representative value for strata of this type. Furthermore, as reported in Table 7-12 of the HA report, anisotropy ratios of up to 250 were permitted during the calibration and hence these values are able to increase where necessary to match observed groundwater level data. An initial anisotropy value of one has been assumed for each of the coal seam layers. In this case, however, given that these layers are relatively thin and therefore more likely to be relatively homogenous, this initial conceptualisation is supported.

For layers other than the coal, single hydraulic parameter values based on the available testing data were assumed initially. Spatial variability in hydraulic parameters (horizontal hydraulic conductivity (Kh), vertical hydraulic conductivity (Kv), specific storage (Ss) and specific yield (Sy)) has therefore only been introduced where necessary to explain the observed data. Initial parameterisation of coal seam hydraulic conductivity is described above in Section 2.1.2. This parameterisation approach is considered to be consistent with good modelling practice whereby additional complexity, in this case spatial variability in modelled hydraulic parameters, is only introduced where necessary to fit the data.

As shown in Table 6-4 of the HA report initial Kh values for each of the three coal seam layers are one to two orders of magnitude higher than the adjacent overburden, interburden or underburden units. This is considered to be consistent with both test data and modelling studies undertaken in similar sedimentary basin settings elsewhere in Australia. In most cases the coal seams represent the most permeable part of the coal measures.

Initial specific yield and specific storage values are also reported in Table 6-4. In terms of specific yield values of 0.5% (or 0.005) were adopted initially for all consolidated layers and between and 0.5 and 2 % (0.005 to 0.02) for the overlying unconsolidated Quaternary and Tertiary aged units. The initial specific yield values adopted for the unconsolidated units are considered to be at or close to the lower end of typical ranges identified in the literature for such strata.

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[3] Office of Groundwater Impact Assessment, 2019, Groundwater Modelling Report, Surat Cumulative Management Area.

For instance, Johnson (1967)[4] suggests values ranging from 1 to 5% for clay, 3 to 12% for sandy clay and 10 to 28% for fine sand. As reported in Table 7-11 some adjustment of these low initial values is allowed during the calibration, however, the adopted upper bound used for calibration is only twice the initial value and hence maximum values allowed during calibration range from 1 to 4% for unconsolidated strata. Given that the unconsolidated strata present in the area are considered to be relatively poor aquifers and include relatively high proportions of clay then relatively low specific yield values are justified to some extent. Sensitivity of model predictions to specific yield values of up to 10% for unconsolidated strata in some instances has also been assessed further as part of the uncertainty analysis (Section 2.2.11).

2.1.4 Seawater intrusion and density dependent flow

Theoretical relationships to estimate the location of the freshwater/saline interface are presented in Figure 6-11 and discussed in the HA report. At the location of the proposed open cut and based on the Ghyben-Herzberg relationship the saltwater interface is reported to be likely to be more than 500 mbgl, more than 300m below the base of the proposed open cut. Accordingly, it is considered unlikely that the position of the saline interface would be affected by dewatering operations. Similarly, the coastal boundary is located sufficiently far from the proposed open cut that the precise nature and location of this boundary condition, which is largely unknown, are considered unlikely to affect predicted impacts significantly. This has also been tested further by the inclusion of an additional predictive scenario incorporating an increased coastal boundary condition elevation (Section 2.2.12).

However, as reported in Section 5.5, many groundwater samples taken in the area in the Quaternary, Tertiary and underlying Permian aged units are highly saline, whilst surface water systems are relatively fresh. These observed density differences and their potential impacts on flows from more saline to less saline areas are not represented in the numerical model. Related to this and as outlined in Section 8.12.3 of the HA report observed groundwater levels have not been adjusted for salinity to produce an equivalent freshwater head on the basis that high groundwater salinities dominate even in alluvial aquifers adjacent to the creeks.

2.1.5 Faults

The most significant fault with respect to propagation of impacts from the proposed open cut is the major fault which marks the edge of the Styx Basin to the east. This fault is intersected by a regional scale section included on the published 1:100,000 scale geological mapping for the area which is reproduced in Figure 4-3 in the HA report. As discussed in Section 4.1.4 of the HA report the estimated displacement of this fault exceeds the thickness of the entire Styx Coal Measures sequence and hence on the upthrown side of the fault to the east the Cretaceous target coal seams (model layers 6, 8 and 10) are in contact with the generally low permeability strata associated with the late Permian Back Creek Group (i.e. model layer 12). Accordingly as shown in Figure 7-2 of the HA report all model layers have been shifted upwards to the east of the fault and a series of MODFLOW-USG 'non-neighbour connections' have been added along the fault contact to create a modelled connection between these strata. As reported in Table 7-11, calibrated Kh for the layer 12 is 0.0004 m/d, whilst the mean calibrated Kh for the coal seams on the other side of the fault is reported to be in the range 0.06 to 0.15 m/d. Hence whilst the fault has not been assumed to be a barrier in the model, the horizontal hydraulic conductivity contrast across it is sufficient to limit the propagation of drawdown impacts (Section 2.2.9).

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[4] Johnson, A. I., 1967, Specific Yield – Compilation of Specific Yields for Various Materials, Hydrologic Properties of Earth Materials, Geological Survey Water-Supply Paper 1662-D, United States Government Printing Office, Washington.

2.1.6 Surface water groundwater interactions

Additional information on surface groundwater interactions in the project area is now available from two level, flow and electrical conductivity (EC) gauging stations installed on Tooloombah and Deep creeks downstream of the proposed open cut. Data for these stations are available for the period from October 2019 to February 2020 and are shown in Graphs 3-6 and 3-7 in the HA report. Data for both gauges show no flow during the period from October 2019 to mid January 2020, and therefore suggests that flow in both creeks is highly ephemeral. This is consistent with estimated flow duration curves for each location, shown in Graphs 3-7 and 3-8 of the HA report, and which suggest flow occurs less than 25% of the time at both sites. However, a series of persistent pools are also observed along both creeks suggesting that even where no flow is occurring the underlying alluvial strata remain close to fully saturated. Monitoring of levels at the Tooloombah Creek gauge site suggests that the pools here are semi-permanent, declining only very slowly (less than around 0.5m in a three month dry period from mid October 2019 to mid January 2020). Well conceived conceptual diagrams showing groundwater-surface water interactions at Tooloombah Creek under a range of different flow conditions are also shown in Figure 6-4 (i to iv).

Two high value wetland areas are also present in close proximity to the proposed open cut. Simple conceptualisation diagrams for these areas are presented in Figure 6.5 (a and b) in the HA report. Multiple lines of evidence are referenced in the report, including isotopic analysis and groundwater level monitoring, and appear to suggest that the water table is more than 10 m below ground level within these wetland areas. Accordingly, the wetlands are thought to be disconnected from regional groundwater systems and largely dependent on surface water sources.

2.1.7 Conceptual water balance

Section 6.3.7 of the HA report presents a partial conceptual water balance. Ideally this section should present pre-modelling estimates of all key inflows and outflows from/to the domain of the numerical model based on the available hydrological and hydrogeological data. Such a balance can identify if there are missing components of the conceptualisation, and whether the assumptions inherent in the conceptual model are plausible. Some estimates of evaporation rates and total volumes of groundwater recharge are provided but there is no tabulation of estimated inflow and outflow terms. In particular a conceptual model of the key discharge components and their relative magnitudes is not provided, although a simple schematic providing basic information is provided in Figure 6-1 of the HA report.

2.2 Review of numerical groundwater model reporting

The development and deployment of a numerical groundwater flow model based on the conceptual model reviewed above is described in Chapters 7 and 8 of the HA report. This forms the detailed reporting of the groundwater modelling and is set out in a logical sequential order and includes a description of the model design and build, the calibration, the predictions and then the model sensitivity and uncertainty analysis.

2.2.1 Model confidence level

For impact assessments the model should be aiming for a Class 2. This is especially the case where, as in this case, sensitive environmental receptors are present in close proximity to the proposed workings.

The assessment completed by HA suggests that the model achieves or even exceeds the targeted Class 2 model confidence level in all categories. For the most part we would concur with this assessment. Two exceptions are described below. Overall, given the targeted confidence level has been achieved for the majority of criteria included in the modelling guidelines, we also conclude that the model can be considered a Class 2 model.

With regard to the adequacy of the streamflow data set we would argue that the current data should be assessed as being Class 1, rather than Class 2 as assessed by HA. Whilst two gauges have been installed on Tooloombah and Deep Creek downstream of the proposed workings only a short period of record is currently available and has not currently been used to calibrate the model, since the only recorded flow event occurred after the end of the model calibration period. Gauges are also not available upstream of the site and hence the rate of actual flow gain or loss from each creek is not known. Hence the Class 2 criteria that reliable streamflow data and baseflow estimates are available at a few points have not been met and the Class 1 criteria of there being little or no useful data on river flows and stage elevations is more appropriate, especially given the limited use which has currently been made of the available data. We note that a comparison of model input creek stages with observed pool levels has been added to the latest version of the report provided for review, for the purposes of model validation. However, this has little/no bearing on this criteria which relates to the availability and use of streamflow data and baseflow estimates.

With regard to the availability of reliable soils and land use data, the HA assessment suggests that the Class 3 requirements have been met. However, as discussed further in Section 2.2.3.3 whilst land-use data is available and is described in Section 3.4 of the HA report it appears not to have been used to parameterise the MODFLOW evaporation package. This has led to the potential simulation of evaporation losses to 8 m below ground level even in areas which have been cleared for grazing and there are few if any deep rooted trees. Accordingly, this is an area where the self-assessed Class 3 requirements have not been achieved, nor for that matter the targeted Class 2 requirements, noting that there is no reference to Class 2 soils and land use data requirements in Table 2-1 in the Australian Groundwater Modelling Guidelines. Fortunately, as discussed in Section 2.2.12, key model predictions appear to be relatively insensitive to the extent of the area modelled using an 8 m extinction depth.

2.2.2 Model structure

Given the objectives of the numerical model and the type and setting of the Project the choice of MODFLOW-USG is considered sound. Similarly, the development of a highly refined mesh in and around the primary areas of interest using HA's AlgoMesh software is commended. Both the particular variant of MODFLOW-USG (USG-Transport) used for the project and AlgoMesh are in widespread use within the groundwater flow modelling industry and as such have been found to be fit for purpose for use in EIS and other projects.

Further utilising MODFLOW-USG capabilities so-called non-neighbour connections have been introduced into the model to allow simulation of areas where hydrostratigraphic units pinch out across mapped faults.

Both the model extent and mesh design are considered to be appropriate based on the predicted extent of impacts. If anything, the model domain is perhaps more extensive than strictly necessary. As mentioned above a variable model mesh has been implemented using AlgoMesh resulting in very small cells of less than 50 m in and around the proposed open cut, faults and nearby creeks increasing to 450 m in other areas more distant from the proposed workings.

2.2.3 Model boundary conditions

2.2.3.1 Coastal boundary condition

The surface processes in the tidal zone of Styx River are dynamic, however on the timeframes that the groundwater model operates it is entirely appropriate to represent this as a constant head and evidence is presented to support the adopted 3.5 mAHD head and extent of the boundary condition. The sensitivity of key model predictions to this adopted value has also been tested by testing higher and lower boundary elevations as part of the scenario based sensitivity analysis (Section 2.2.12). This analysis concluded that key model predictions were insensitive to this boundary assumption. This finding is considered to be consistent with the elevated distance (around 25 km) of this coastal boundary from the proposed open cut pit.

2.2.3.2 Creek boundary condition

As shown in Figure 7-4 of the HA report, the lower sections of Tooloombah Creek from just upstream of the proposed open cut to the tidal limit has been represented using the MODFLOW river package and assuming a river stage which is 1 m above the top of the modelled river bed. River cells parameterised in this way effectively represent a form of constant head boundary where the volume of flow gained or lost by each river cell is governed by: i) the head difference between the river and the 'underlying' model layer; and ii) the river bed conductance. Given the proximity of Tooloombah Creek to the proposed open cut the choice of boundary condition for this water course is a key component of the model design. In particular the choice of a boundary condition which represents an infinite source of water so close to the open cut has the potential to lead to under-estimation of the potential impact zone. Typically, the river package would be used to represent perennial water courses where the volume of flow in the water course is orders of magnitudes higher than the stress being assessed. In this case however, as discussed in Section 2.1.6, Tooloombah Creek is highly ephemeral and flows for less than 25% of the time. Accordingly, for more than 75% of the time there would be little to no flow available to leak into the underlying aquifer. The use of MODFLOW river cells which represent a potentially infinite source would not normally be advisable in such a scenario since in reality the volume of water which can leak from the creek is likely to be limited by the flow in the creek for the majority of the time. However, as discussed in Section 2.1.6 monitoring of surface water levels in Tooloombah Creek also suggests the existence of semi-permanent pools which in turn indicates that the underlying strata remain saturated even during extended dry periods. Furthermore, the predicted volumes of seepage (see Section 2.2.8) represent only a small proportion of estimated average flow in the creek. The use of the MODFLOW river boundary condition at this location is therefore considered to be defensible, although an additional impact sensitivity run was recommended in the Stage 3 peer review to confirm the degree to which model predictions are sensitive to the use of this boundary condition. The results of this additional run are presented in Attachment 18 of the HA report and discussed further in Section 2.2.12.

All other river cells in the model domain have been parameterised such that they act like drains (by setting the river stage and modelled river bed to the same value) and can only remove water from the model domain. This is considered to be consistent with the ephemeral nature of these creeks, the lack of permanent pools, and in terms of lateral propagation of impacts is also considered to represent a conservative approach.

2.2.3.3 Evaporation

Extinction depths used to parameterise the MODFLOW evaporation package are reported to be based on maximum rooting depths for different vegetation types reported in Canadell et al (1996) and Shah et al. (2007). Canadell et al (1996) suggest maximum rooting depths for trees of 7-8 m, shrubs 5-6 m, herbaceous plants 2.5 m and crops 2 m. These depths are considered to be reasonably consistent with other similar studies and suggest that root depth and hence evapotranspiration losses are related to the type of ground cover or land use. As described in Section 3.4 of the HA report, land use in the model domain is dominated by agriculture (78%) predominantly grazing. However, rather than base modelled extinction depths on land use mapping it would appear based on Table 7-6 in the HA report that they have been based on outcrop geology mapping such that all areas mapped as Qpa, Qr, Qf and Qa on regional geology maps have been assigned extinction depths of 8 m. As shown in Figure 2.1 this results in extinction depths of 8 m being assumed across the majority of the modelling domain, despite clearing of the majority of this area for grazing purposes. Accordingly the Stage 3 review recommended a further impact sensitivity run be undertaken to confirm the sensitivity (or otherwise) of model predictions to the current extinction depth assumptions. The results of this additional run are presented in Attachment 18 of the HA report and discussed further in Section 2.2.12.

The very high evaporation losses predicted in isolated areas, particularly towards the southern boundary of the domain shown in Figure 2.2, were also queried with the modelling team during the Stage 3 review and attributed to high modelled water tables in Tertiary outcrop areas. Given the distance of these areas from the proposed mining operations this is considered unlikely to materially affect predictions.

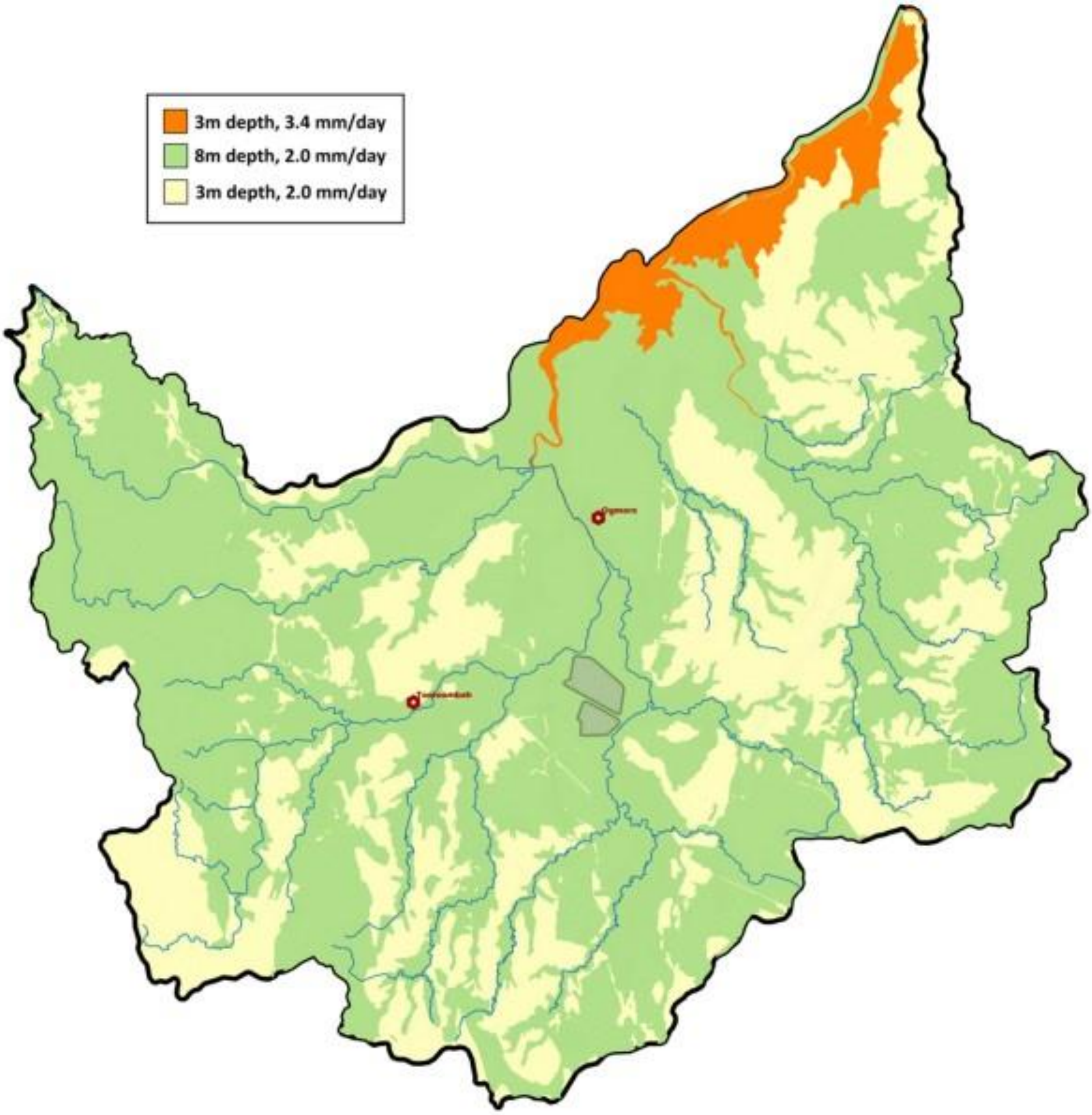

Figure 2.1 Maximum rate and extinction depths applied across the model domain (Figure 7-7, HA report)

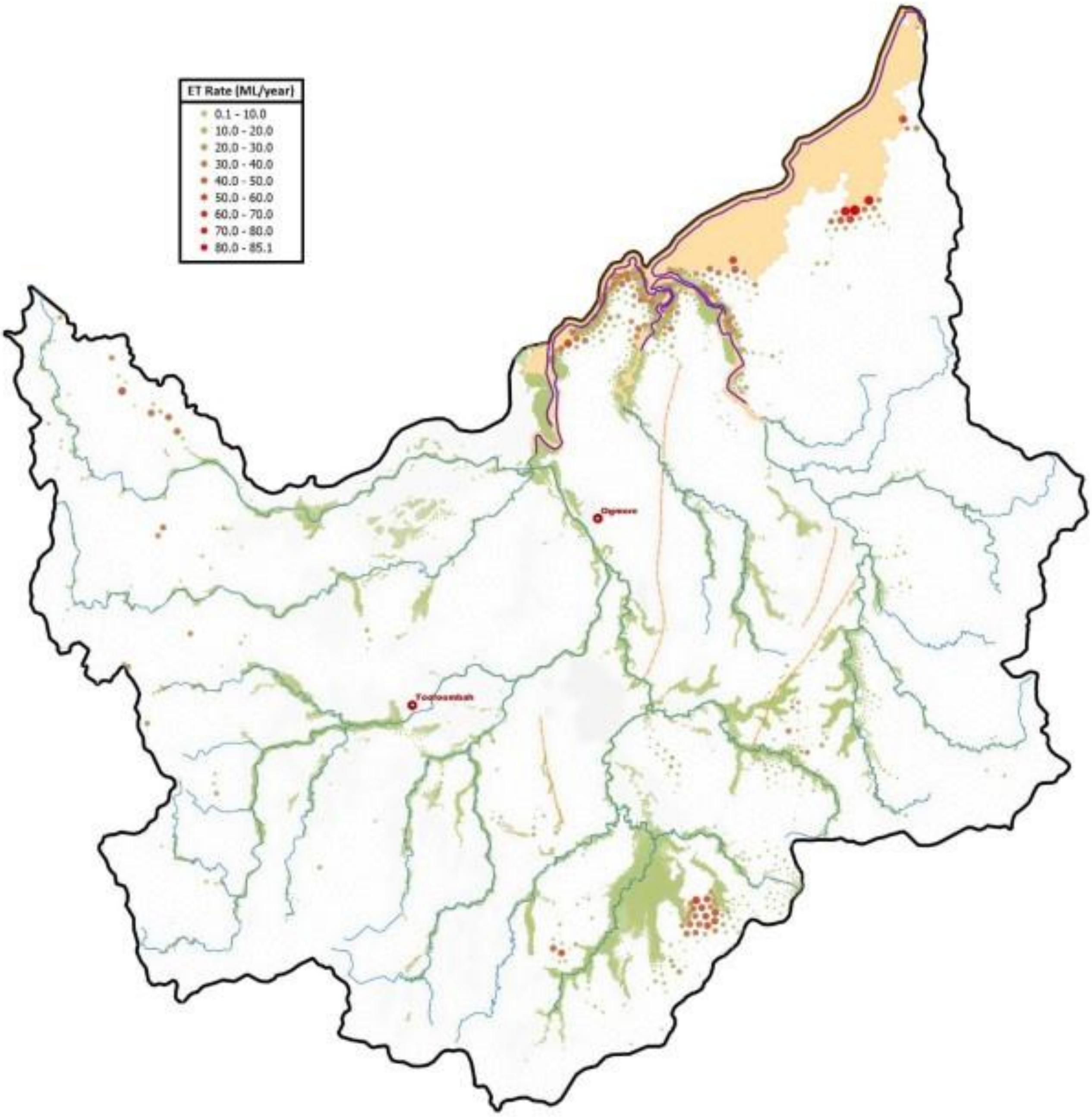

Figure 2.2 **Modelled evapotranspiration flux rates across the model domain (Figure 7-11, HA report)**

2.2.3.4 Groundwater extraction

Existing groundwater extraction from landholder bores has not been included in the model. Existing extraction is, however, understood to be limited to a relatively small number of stock and domestic extractions. The exclusion of these bores is considered to be a reasonable simplification and unlikely to affect the ability of the model to predict project impacts.

2.2.4 *Representation of dewatering*

Proposed open cut mining is represented in the model using the MODFLOW drain package which is an appropriate approach for the likely dewatering method being a pumped sump within the working pit. As described in Section 8.3.1 of the HA report, advanced dewatering using groundwater extraction bores is under consideration but would involve the construction of sacrificial bores within the proposed open cut footprint, rather than outside it. Accordingly, assuming that these bores are not drilled more than say one year in advance of the proposed open cut then no material effects on either the magnitude or timing of impacts would be expected.

2.2.5 *Model approach and steady state*

The calibration simulation is reported to comprise a steady state calibration to provide initial conditions prior to two transient models of the historic period as follows:

- an initial transient model of the period from 1919 to December 2010 include representation of historic mining activities in the vicinity of Bowman (1918 to 1948) and Ogmore (1924 and 1964); and
- a second transient model of the period from January 2011 to September 2019.

As there is no historic groundwater level data prior to January 2011, then only the steady state model and the second transient model of the more recent period have been calibrated. The transient simulation of the period from 1919 to 2010 therefore acts to provide realistic water levels for the start of the second transient calibration. Both steady state and transient calibration models have been calibrated to groundwater levels only. No flux or head difference targets at nested monitoring locations have been included in the calibration, although observed head differences were compared to modelled equivalents post calibration as shown in Graph 7-4 in the HA Report.

2.2.6 *Backfilling, final voids and elevated landforms*

Progressive backfilling of the open cut using coal rejects and waste rock blended with overburden spoil has been simulated using the time-varying material (TVM) package to simulate the change in hydraulic properties that will occur as natural strata are replaced with backfill. Consistent with the unconsolidated nature of the material emplaced, relatively high hydraulic conductivity (Kh = 1 m/d) and storage properties (Sy = 20% and Ss = 1.3×10^{-5} 1/m) have been assumed for the backfill. Previous work undertaken by Dawkins (1998)[5] is referenced as being the basis of the Kh value adopted. An increased recharge rate of 5% of rainfall has also been assumed for backfilled areas (i.e. 3 to 8 times higher than adjacent unconsolidated Quaternary strata) on the basis that the backfill will likely comprise broken rock with limited fine material.

The same hydraulic conductivity, storage, recharge and evaporation parameters described above have also been assumed to apply to two out of pit waste rock emplacement areas which form part of the final landform. These waste rock areas, which attain elevations of around 75 m above pre-mining levels in places, have been simulated in layer 1 of the model and lead to predicted post development increases in discharge to local water courses. This is discussed further in Section 2.2.9 below.

All open cut areas are to be backfilled during mine closure, presumably to above the water table. Accordingly, no simulation of long term water levels in residual mine voids have been undertaken.

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[5] Hawkins, J.W. (1998) Hydrogeologic Characteristics of Surface-Mine Spoil. In Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania, ed. Brady, Smithy and Schueck. Harrisburg, Pennsylvania.

2.2.7 Model calibration

Calibration of the model was undertaken by varying model parameters relating to horizontal hydraulic conductivity (Kh), anisotropy, specific yield, specific storage and recharge (via calibration of the modelled ratio between modelled Kh and rainfall infiltration rate). Modelled conductance values assigned to river cells were not adjusted during the calibration on the basis that no flow events were observed during the calibration period.

A range of outputs are provided in the HA report from which the calibration performance can be assessed, although only limited information is provided on how the calibration was achieved. The reporting suggests that the model was calibrated manually initially before being subject to automated calibration using the PEST suite of software. No further information on the precise methodology adopted (PEST supports a range of different approaches) or on matters such as observation weighting which can significantly affect the success of the calibration are provided. Nevertheless, a low calibrated Scaled RMS (SRMS) statistic of 2.0% is reported for the transient calibration, which suggests that across the model domain as a whole the model is able to replicate observed heads relatively well. The availability of calibration data in the Styx Coal Measures particularly in and around the proposed open cut area has been substantially improved compared to previous iterations of the project EIS.

Maps showing modelled head residuals in various model layers are shown in Figures 7-9 and 7-10 in the HA report. For the most part few if any spatial patterns, which can indicate systematic errors in the model, are evident. However, Figure 7-10b which shows modelled residuals in the Styx Coal Measures suggests a tendency for the model to systematically either under (or over-predict) observed heads in this unit. It is not clear from the legend on these figures whether negative values indicate under prediction or vice versa, although this has been clarified in the accompanying text.

As mentioned previously in Section 2.2.5 the current calibration relies solely on absolute groundwater level observations and is therefore likely to be prone to a relatively high degree of non-uniqueness, compared to a model that has been calibrated to a range of different observation types. Accordingly, the predictive uncertainty analysis is considered to be particularly important for this model. Additional data which could have used for model calibration include observed:

- flows at the recently installed Tooloombah and Deep Creek gauges, although it is recognised that this would have required extension of the current model calibration period after completion of the bulk of the modelling work;
- water levels in semi-permanent pools along the Tooloombah and Deep creeks; and
- head differences in nested monitoring points.

In the reviewer's opinion, the inclusion of these additional targets would likely have improved the overall calibration and reduced predictive uncertainty by reducing the potential for non-uniqueness in the solution.

Calibrated hydraulic parameters for each layer are summarised in Tables 7-12 and 7-13 and in maps included as Attachment 12 in the HA report. For the most part the final calibrated values are considered plausible. In some cases reported mean values for layers are at either the adopted upper and lower bounds suggesting that the ranges adopted for calibration may have been too restrictive. However, the sensitivity of model predictions to this restriction was subsequently assessed during the uncertainty analysis by assessing a range of parameters either side of the calibrated value (Section 2.2.11).

2.2.8 Modelled water balance

A modelled water budget for the transient calibration period is presented in Table 7-15 in the HA report. The dominant modelled output is reported to be evapotranspiration (67.7 ML/day) which represents around 83% of the modelled total inflows. Further information on the distribution of these evaporation losses is provided in Figure 2.2. For the most part the distribution of evaporation losses shown in Figure 2.2 appears sensible and is largely confined to topographically low areas where the water table is likely to be relatively high allowing groundwater supported evapotranspiration to take place. Water budget results also show only minor discharge (3.2 ML/day) to surface water courses (i.e. baseflow) suggesting that the majority of water is lost as evapotranspiration in the riparian corridor before entering the creeks. This is consistent with the highly ephemeral nature of the creeks in the area. Elevated evapotranspiration losses are, however, modelled in isolated areas in cells adjacent to the coastal fixed head boundary condition towards the north of the model. The elevated losses close to the northern boundary related to evaporation being applied to cells adjacent to the constant head boundary elevation of 3.5 mAHD. To meet this evaporation demand water is being pulled from the offshore area which explains the relatively large volume of inflow (19.1 ML/day) from constant head cells reported in the modelled water budget. It seems unlikely that this flow is actually occurring in practice, however, given that the proposed open cut is some distance from this coastal boundary this is unlikely to affect any of the key impact predictions.

2.2.9 Predictions

As reported in Table 7-9 of the HA report impact predictions have been derived based on a comparison of modelled heads and flows in two scenarios: a transient prediction model (in which the Project is represented) and a transient null model (which excludes the Project). This approach is consistent with guidance included in the Australian groundwater modelling guidelines since this differencing approach can reduce uncertainty in the drawdown estimates.

Predicted groundwater inflow to the two proposed open cuts is presented in Graph 8-1 of the HA report, a snapshot of which is presented below (Figure 2.3). The pattern of flows presented is plausible suggesting a relatively rapid increase in inflow during the initial development period, falling gradually thereafter as areas are progressively backfilled.

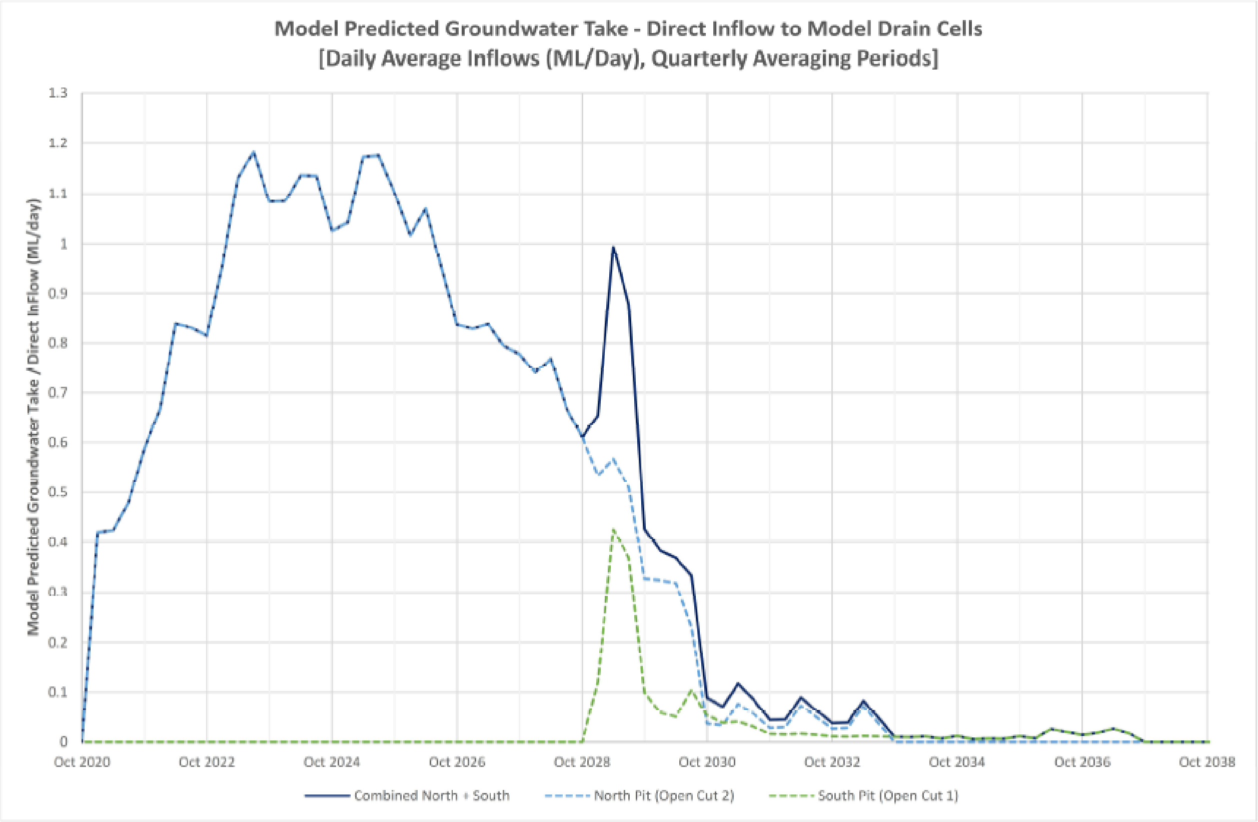


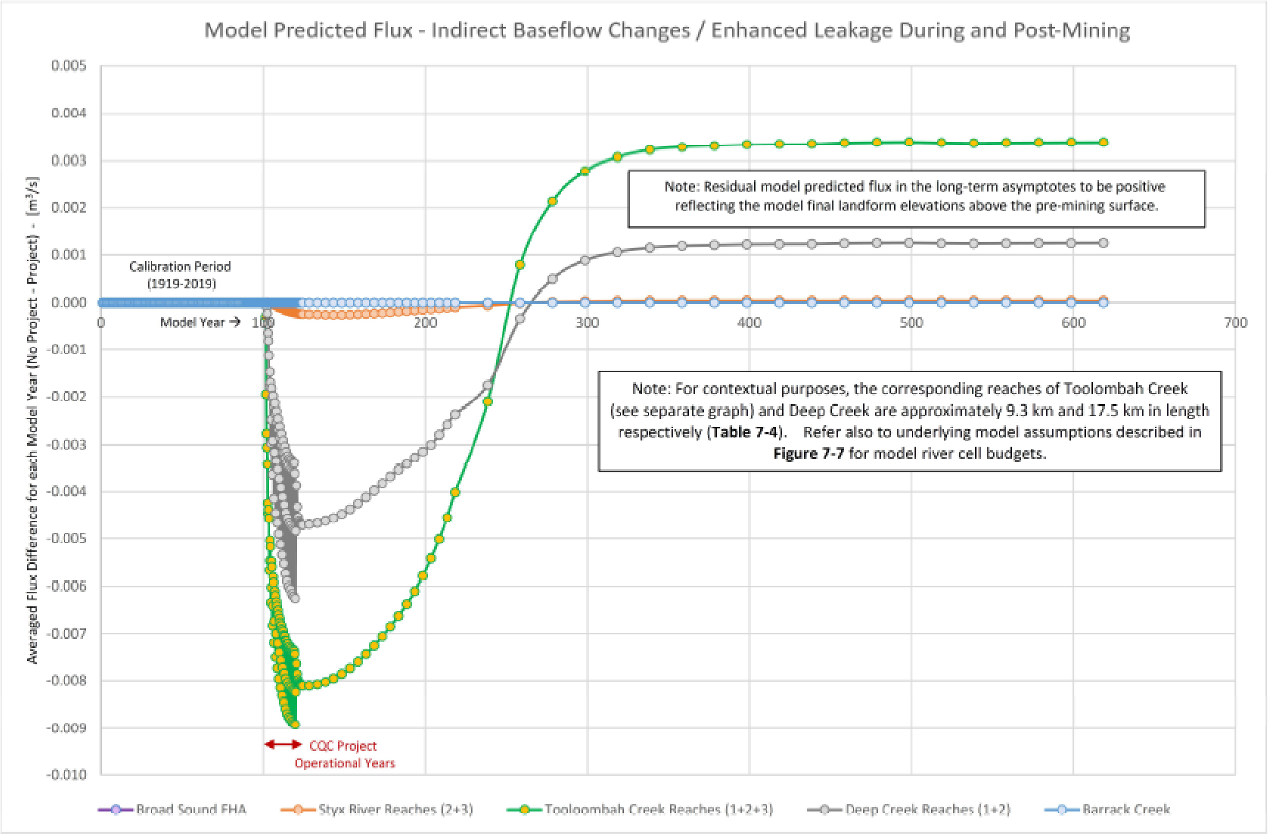
Figure 2.3 Modelled predicted groundwater take – direct (daily average) inflow to Modelled Drain Cells [2020 to 2038] (Graph 8-1, HA report)

It should be stressed, however, that this plot is reported to be based on modelled drain flows only. Elsewhere the reporting suggests that evaporation may also be occurring from those parts of the open cut areas which have been backfilled. However, subsequent analysis of the raw model files provided suggests that this is not the case and that evaporation would only occur from backfilled areas once groundwater levels rise to within 8 m of the final post development ground level. As this is likely to only occur well after mining operations cease then modelled evaporation losses from the open cut area during mining are likely to be insignificant.

Maps showing predicted drawdown in most model layers at various times as well as maximum all-time drawdown contours are presented in Attachment 14 of the HA report. Predicted maximum impacts at four nearby private landholder bores are tabulated in Table 8-4 of the HA report. Of these only one bore is listed as being potentially impacted by more than the relevant Water Act 2000 trigger threshold of 5 m for consolidated strata.

Predicted reductions in groundwater flow to Tooloombah and Deep creeks and other water courses are shown in Graph 8-3 of the HA report, a snapshot of which is presented below (Figure 2.4). As shown maximum impacts of up to 0.009 m^3/s (equivalent to 0.78 ML/d) are predicted during mining in Tooloombah Creek, up to around 0.006 m^3/s (equivalent to 0.52 ML/d) in Deep Creek and little or no impacts on groundwater discharge to other creeks. During the review process it was noted that these predicted impacts represent a significant proportion of the predicted mine inflows (Figure 2.3) particularly towards the end of the mine life. However, subsequent sensitivity runs testing different river bed conductance values (Section 2.2.12) suggested that the similarity of these flows was coincidental.

Post mining predictions suggest slight increases in flow to both Tooloombah and Deep creeks due to additional groundwater discharge from two out of pit waste rock emplacement areas which form part of the final landform. As discussed previously in Section 2.2.6 this is in part due to the relatively high recharge rates assigned to these waste rock emplacement areas.



Note: Residual model predicted flux in the long-term asymptotes to be positive reflecting the model final landform elevations above the pre-mining surface.

Note: For contextual purposes, the corresponding reaches of Toolombah Creek (see separate graph) and Deep Creek are approximately 9.3 km and 17.5 km in length respectively (**Table 7-4**). Refer also to underlying model assumptions described in **Figure 7-7** for model river cell budgets.

Figure 2.4 Model predicted flux – indirect baseflow changes/enhanced leakage during and post mining (Graph 8-3, HA report)

2.2.10 Identifiability analysis

The fatal flaw checklist provided in the IESC Uncertainty Analysis Guidance Note (Middlemiss and Peeters, 2018, Section 2.4) includes a requirement that a parameter sensitivity and/or parameter identifiability analysis be completed and the implications discussed. In this case a parameter identifiability analysis has been undertaken. In keeping with the rest of the technical report a wealth of detail on the results of this analysis are presented in Section 8.11.1 and Attachment 16 of the HA report. Some of the implications of this analysis are also discussed as required by the IESC.

However, it should be noted that this analysis has been limited to the same parameters which were varied during the calibration (i.e. horizontal hydraulic conductivity, anisotropy, specific yield and specific storage, and recharge, Section 2.2.7). Accordingly, the sensitivity of observations to a number of other model parameters including river bed conductance in particular do not appear to have been assessed.

2.2.11 Uncertainty analysis

An uncertainty analysis has also been undertaken using a stochastic modelling approach which is considered to represent the most robust of the three techniques identified in the IESC guidance note. The results of the quantitative analysis based on 602 calibration constrained predictive model runs are presented in Section 8.11.2 and Attachment 11 of the HA report. The attachment in particular provides a large amount of detail and output relating to the analysis.

This includes a detailed consideration of whether or not sufficient predictive runs were undertaken to generate reliable statistics. Key results are also well presented in summary form in Table 8-8.

The Stage 3 peer review highlighted three aspects of the uncertainty analysis relating to the model parameters and parameter ranges investigated and the SRMS cut off applied which were discussed further with the HA modelling team and ultimately satisfactorily resolved as described below.

With regard to the parameters assessed as part of the uncertainty analysis this was limited to the same parameters assessed during the calibration and identifiability analysis (i.e. horizontal hydraulic conductivity, anisotropy, specific yield, specific storage and recharge parameters). River bed conductance was therefore excluded from analysis. However, the sensitivity of key predictions to this parameter has now been assessed via an additional sensitivity scenario, as described in Section 2.2.12.

With regard to appropriate parameter ranges and SRMS cut offs there is no specific advice in the relevant guidelines as to what ranges or cut offs should be used and the guidelines recognise that the modellers themselves are best placed to make such subjective decisions, since they have the most complete understanding of the model sensitivities. In this case the modellers have investigated a range of alternative parameter sets 95% of which fall within one order of magnitude of the calibrated value for all parameters excluding specific yield. For specific yield a narrower range of alternative parameters with 95% of values falling within a factor of two of the calibrated range has been assessed. It is noted that in some cases the parameter ranges explored in the uncertainty analysis are more restrictive than those considered acceptable in the model calibration (Table 7-12 in the HA report).

Furthermore, a relatively narrow calibration constraint has also been adopted, whereby any run where the SRMS exceeds 3% has been excluded from the analysis on the basis that it is inconsistent with the observations. It is recognised that a SRMS value of 3% represents a calibration that is statistically 50% worse than the fully calibrated model, which achieved a SRMS of 2%. However, a SRMS of up to 10% is often considered acceptable in many modelling studies and hence a model achieving a SRMS of 3% would still generally be considered to be very well calibrated and hence not inconsistent with the data.

The review process also investigated why outputs generated using the baseline fully calibrated (LF3) parameter set to the 90th percentile of some key impact metrics (see Figure 2.5 and Figure 2.6) and close to the 10th percentile in others (see Figure 6 in Attachment 11 of the HA report). Given the approach adopted to generate alternative parameters for the uncertainty analysis described above, whereby the generated parameters were centred on the calibrated value, this was thought to be somewhat unusual, suggesting a possible bias in the values generated. However, subsequent analysis of the full parameter set generated for all 1,000 uncertainty analysis runs provided by HA confirmed that this was not the case. The only systematic 'bias' evident in the parameters sets related to the anisotropy of layers 12, 13 and 14. For these three layers an anisotropy value of one was calibrated and any parameters of less than one generated during the uncertainty analysis were justifiably rejected as being unrealistic. All 1, 000 alternative anisotropy values generated for these layers in the uncertainty analysis were therefore higher than the fully calibrated LF3 parameter set.

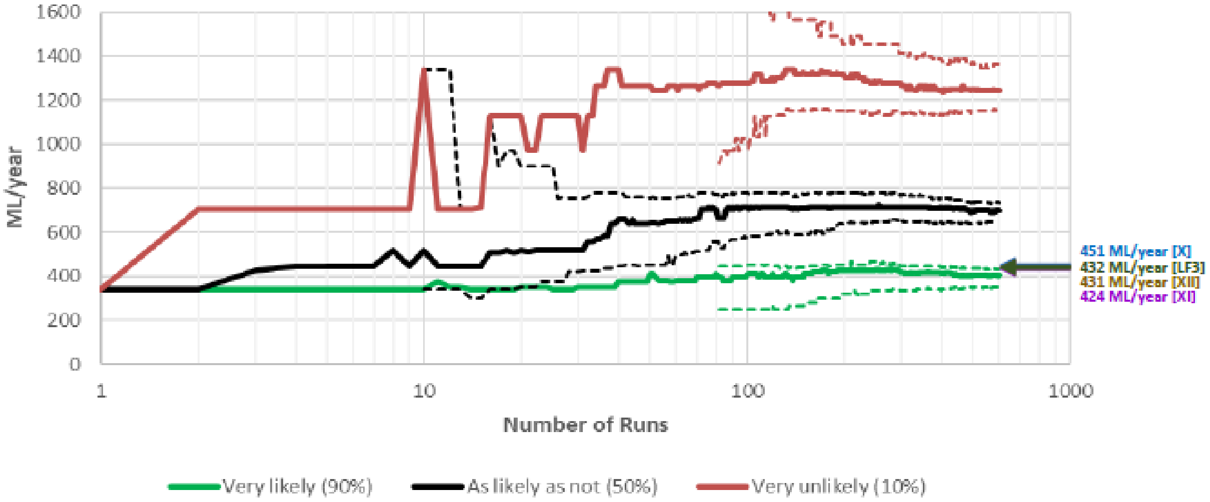


Figure 2.5 99.7% Confidence Intervals of Probability of Exceedance – Peak Mine Inflows [Combined] – Additional Parameter Analysis Comparison with LF3 (Graph 8-6, HA report)

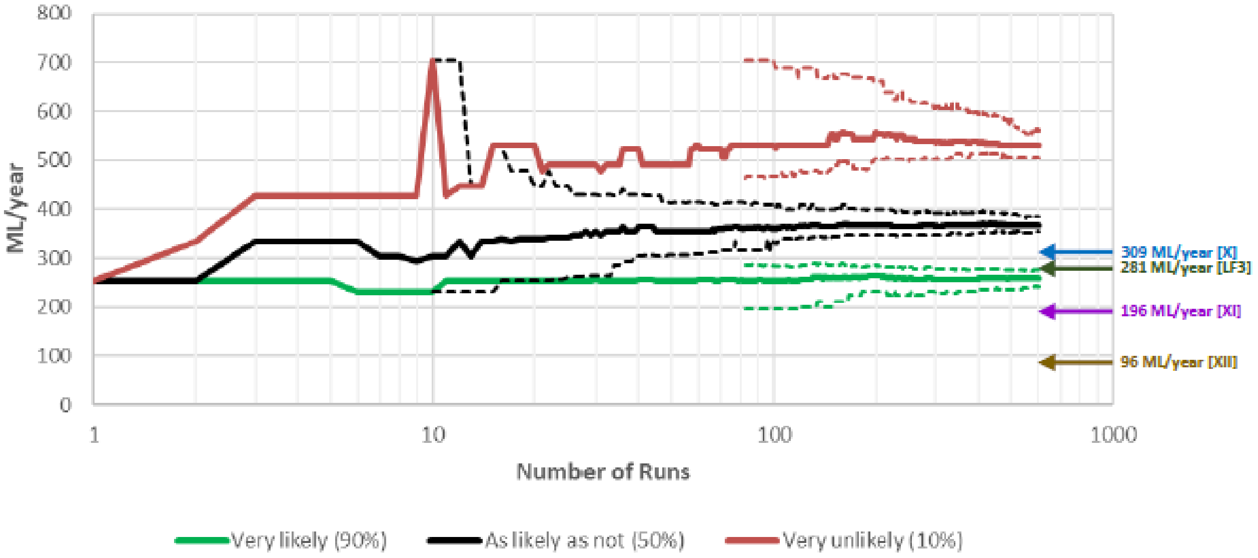


Figure 2.6 99.7% Confidence Intervals of Probability of Exceedance – Peak Baseflow/Leakage Change for Tooloombah Creek– Additional Parameter Analysis Comparison with LF3 (Graph 8-7, HA report)

2.2.12 Scenario based sensitivity analysis

A series of additional scenarios were undertaken as described in Section 8.11.3 of the HA report to assess the impacts of different coastal boundary and fault connectivity assumptions and potential climate changes. A further three scenarios (Scenarios X, XI and XII) were also undertaken as described in Section 8.11.6 of the HA report to assess the degree of sensitivity of key model predictions to:

- the 8 m evaporation extinction depth applied across large parts of the model domain (Section 2.2.3.3), Scenario X;
- test an alternative boundary condition assumption or conceptual model, in which leakage from Tooloombah Creek is assumed to be insignificant (Section 2.2.3.2), Scenario XI; and
- modelled river bed conductance, since this parameter was not included in the predictive uncertainty analysis (Section 2.2.11), Scenario XII.

Revised predictions based on these three additional scenarios are summarised in Attachment 18 of the HA report and also in Figure 2.5 and Figure 2.6 (above). Results for Scenario X tend to confirm that key model predictions are relatively insensitive to the extent of the area modelled using an 8 m extinction depth. However, results for Scenarios XI and XII suggest that key modelled predictions are relatively sensitive to the river bed conductance parameter. As would be expected reducing the river bed conductance generally results in less predicted leakage from the Tooloombah Creek (Figure 2.6) but also results in a more extensive area predicted to experience more than 2m of drawdown than that predicted using the fully calibrated LF3 parameter set or the 10th percentile of the uncertainty analysis output.

2.3 Review of model files

The review of the supplied model files involved rerunning the models locally and comparing the model files against what has been reported. This was undertaken, and the model output was extracted from the model output files (such as heads) and examined in a GIS package. The reported water balance in the model output 'listing' files were also examined from the supplied model runs. Some aspects of the detail of the evaporation package were also confirmed through examination of the relevant MODFLOW input files.

No significant discrepancies between the model reporting and model files were identified. Some minor differences in the modelled water balance were identified between output generated by an AGE re-run of the transient model with output provided by HA. However, this re-run was undertaken using a standard version of MODFLOW USG and a standard CPU based solver, whilst the HA output was generated using a proprietary GPU based solver developed by HA. Whilst this bespoke solver does result in significantly lower run times is does appear to come at the cost of slightly higher modelled water balance errors. However, errors using both solvers were substantially less than the 1% threshold typically considered acceptable in similar numerical modelling studies.

2.4 IESC Uncertainty Analysis Guidance Note review checklist

As mentioned previously in Section 2.2.10 the IESC Uncertainty Analysis Guidance Note includes a review checklist which it is recommended be applied to projects which include an uncertainty assessment. This checklist includes the following items:

1. Is there evidence of engagement ("without prejudice") between the project proponent and regulatory agencies from the project outset and at subsequent key stages
2. Is the modelling and uncertainty analysis methodology designed to provide information for decision makers on the effects of uncertainty on the project objectives (echoing the definition of risk in AS/NZS ISO31000:2009) and on the effects of potential bias?
3. Are the adopted conceptual model, complexity–simplicity balance and applied modelling package capabilities commensurate with the overall risk context and the models purpose of investigating the uncertainty/risk issues (i.e. based on the evidence available of engagement identified in item 1)?
4. Has the uncertainty assessment and modelling methodology been designed and implemented using all the available data? Detailed consideration of the hydrological stressors arising from the development and of natural stressors, including climate variability, and unbiased consideration of water-related asset values and causal pathways for potential impacts (direct, indirect and cumulative) should be provided.
5. Where history-match conditional calibration is undertaken, has it minimised non-uniqueness and error variance (using approaches recommended in the AGMG)? If not, is a reasoned justification provided? Is an acceptable level of model-to-measurement mismatch defined for the conditional calibration?

6. Are all simulations consistent with all relevant information/data (using approaches recommended in the AGMG)? If not, is a reasoned justification provided?
7. Has the model been submitted to stress testing in which a number of extreme parameter combinations (representing a computationally intensive automated conditional calibration or stochastic model evaluation) are tested for model convergence?
8. Has a parameter sensitivity analysis and/or a parameter identifiability analysis been completed to identify which parameters can be constrained by the available observations and which parameters affect the simulations the most? Are the implications discussed?
9. Have all reports been prepared in an open, honest and transparent way that is:
    i. open to independent scrutiny and not prone to misinterpretation;
    ii. based on agreed and transparent model objectives;
    iii. tailored to decision-makers' needs (focusing on messages relevant to their decisions); and
    iv. presented in plain and clear language (precise, jargon-free, calibrated), with useful graphics.

Inevitably any assessment of whether or not a modelling study meets a set of criteria is subjective. For the most part, in the opinion of the peer reviewers, the modelling study at least partially meets the requirements as laid out in the IESC Uncertainty Analysis Guidance Note. however, two areas where this assessment is not clear cut are discussed below.

2.4.1 Checklist Item 3 – development of models commensurate with the overall risk context

Given the sensitivity of some of the potential impact receptors of the project which include high priority wetlands and the Great Barrier Reef Marine Park (i.e. a high overall risk context) then it could be argued that development of more integrated surface water and groundwater models should have been undertaken. However, it is understood that this is being addressed by the development of a separate integrated surface water – groundwater model developed by Eco Logical Australia Pty Ltd, although the peer reviewers have no direct knowledge of this work.

2.4.2 Checklist Item 5 – has the calibration minimised non-uniqueness

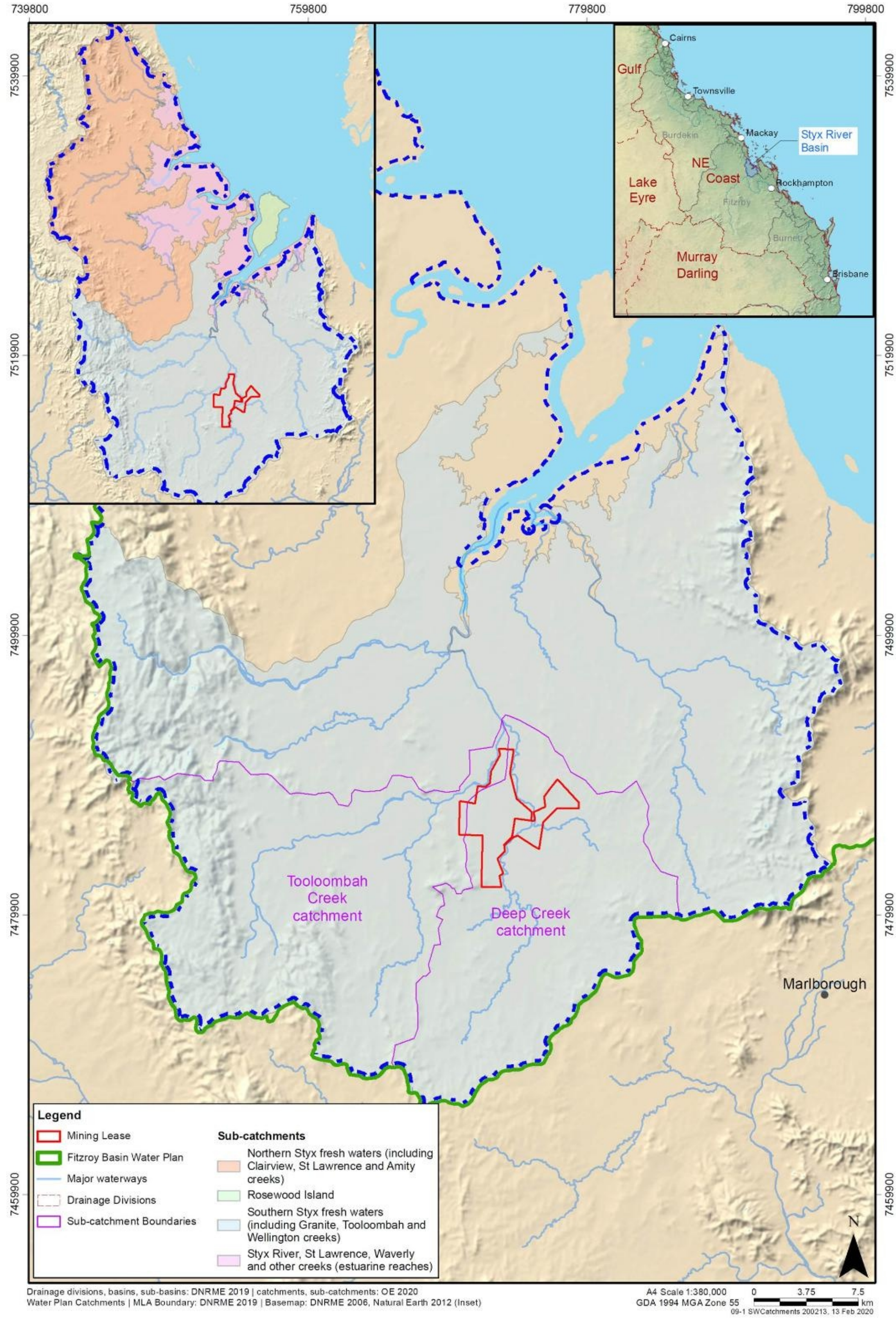
As discussed in Section 2.2.7 due partly to data limitations calibration has been undertaken to observed groundwater levels only and is likely therefore to be more prone to non-uniqueness than if other types of calibration data were available. The sensitivity of key model predictions to non-uniqueness has been assessed through the development of more than 600 alternative calibration parameter sets as part of the uncertainty analysis (Section 2.2.11). However, not all parameters were included in this analysis and the parameter ranges used were arguably too narrow. This has been addressed, to some extent, through the completion of two additional scenarios to assess the sensitivity of key predictions to the river bed conductance parameter (Section 2.2.12).

3 Concluding statement

The groundwater assessment and supporting groundwater modelling work described in the HA report and various attachments have been carried out in a professional and rigorous manner that meets current industry standards. The modelling work has generally been completed in line with the Guiding Principles included in the Australian Groundwater Modelling Guidelines and in the IESC Uncertainty Analysis Guidance Note and we have not identified any fundamental flaws in the work which are likely to significantly effect model predictions. We note that Section 10.9 of the HA report includes a commitment to review the project numerical model at least every three years from the commencement of open cut mining. We agree with this approach and based on the findings of this review we suggest as a minimum that the following two items below be addressed in the first such iteration:

- Re-calibration of the groundwater flow model to observed head differences in nested monitoring facilities and to estimated baseflow at the Tooloombah Creek and Deep Creek gauges; and
- Re-running the predictive uncertainty analysis including the river bed conductance parameter, assessing a wider range of parameter values and adopting a higher SRMS cut off.

ATTACHMENT 3
FIGURES



Drainage divisions, basins, sub-basins: DNRME 2019 | catchments, sub-catchments: OE 2020
Water Plan Catchments | MLA Boundary: DNRME 2019 | Basemap: DNRME 2006, Natural Earth 2012 (Inset)

Figure 2-1

Fitzroy Basin Waters (Relative to Styx Surface Water Basin)

[*Source: CQCPL, 2020*]

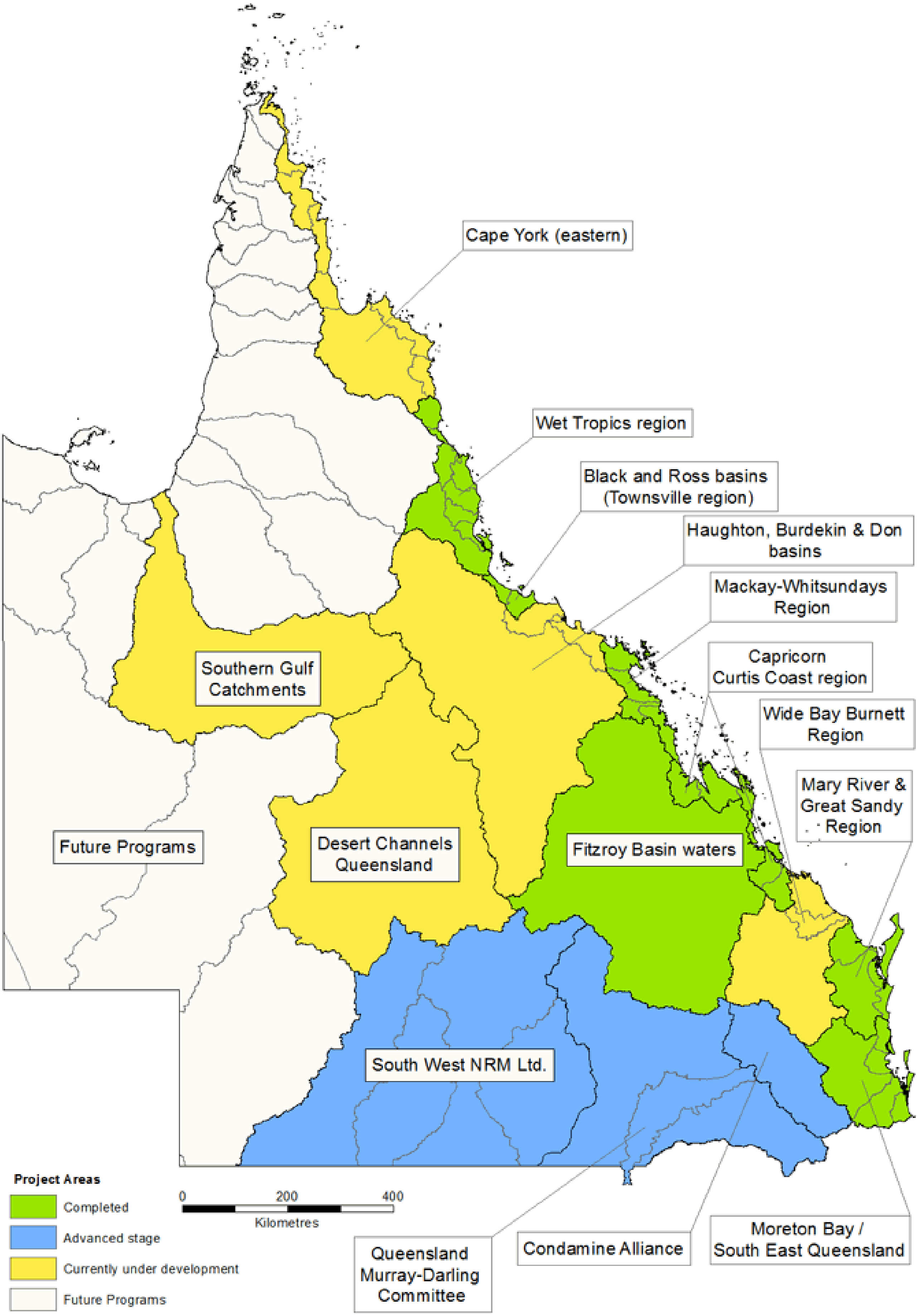


Figure 2-2

Capricorn Curtis Coast Region - Areas Scheduled under the *Environmental Protection (Water and Wetland Biodiversity) Policy 2019*

[*Source: Qld Government, 2019*]

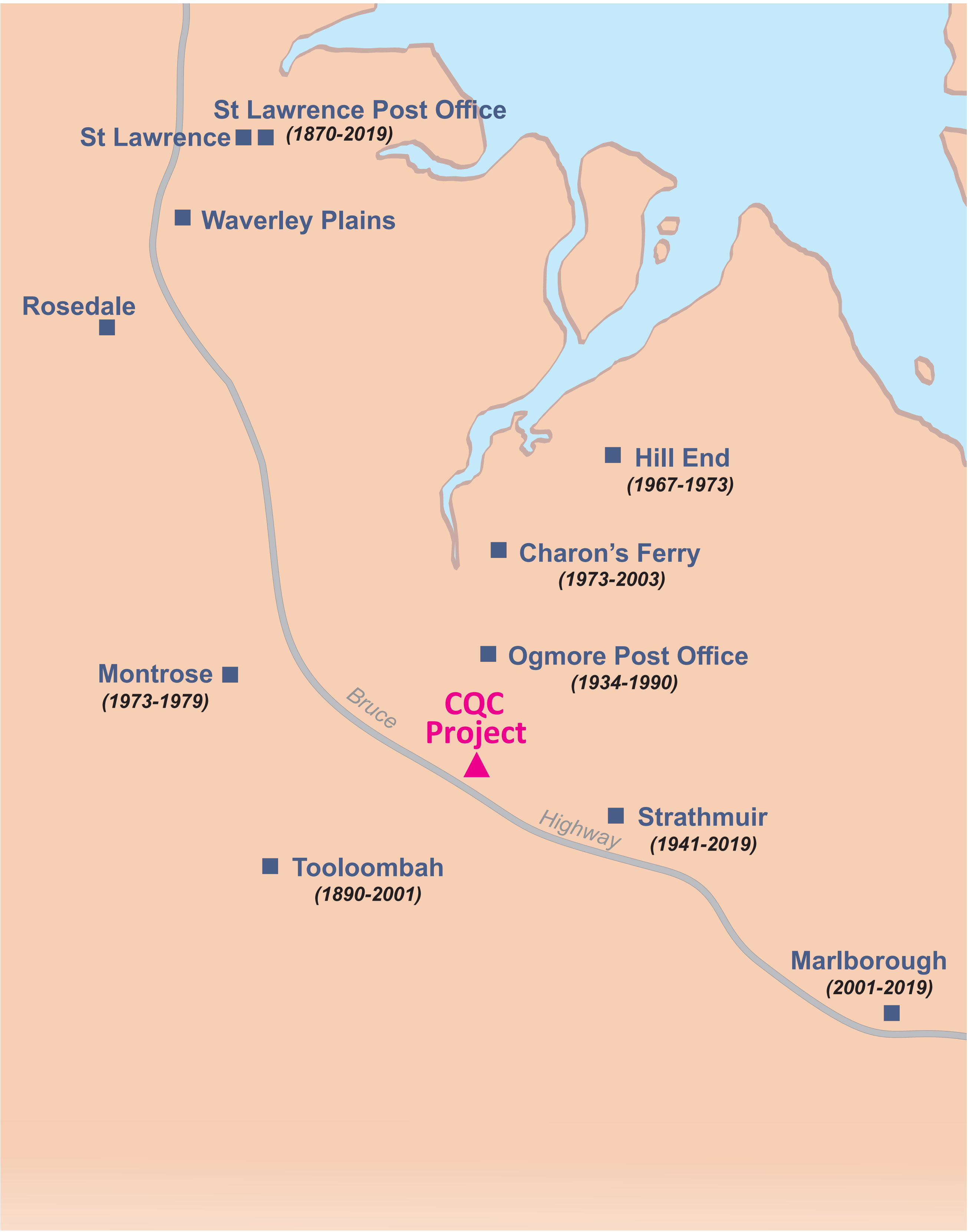
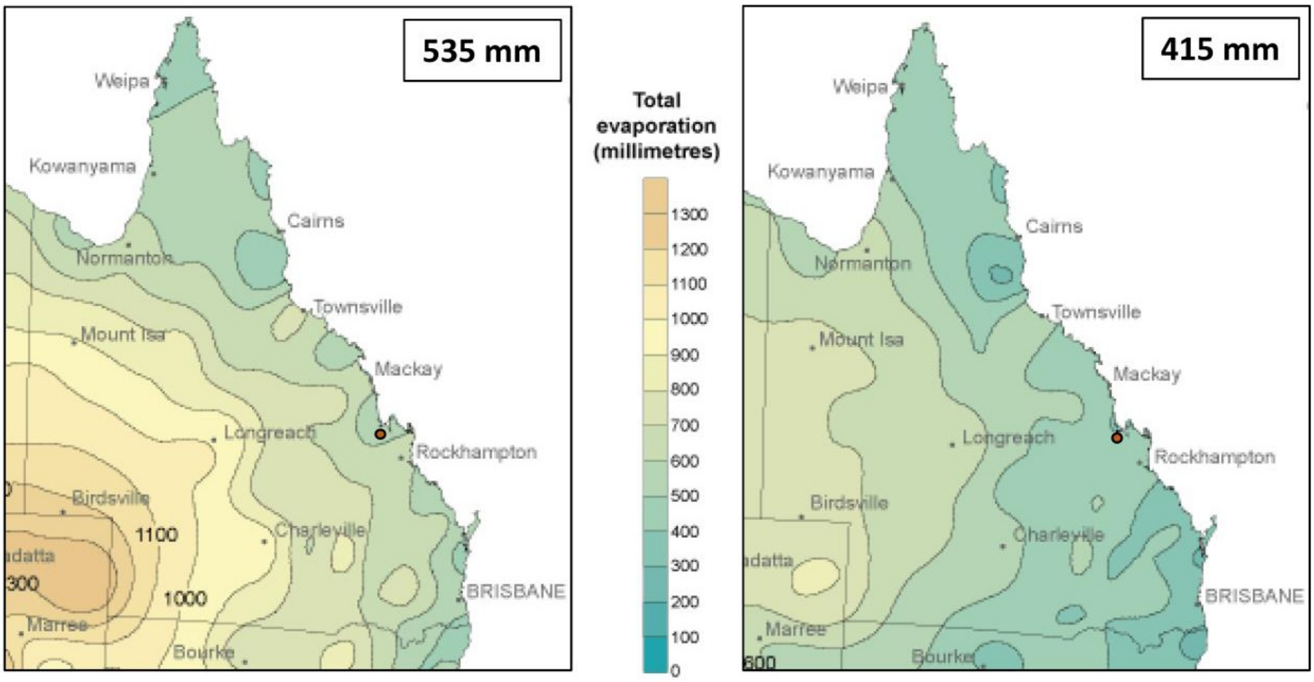


Figure 3-1

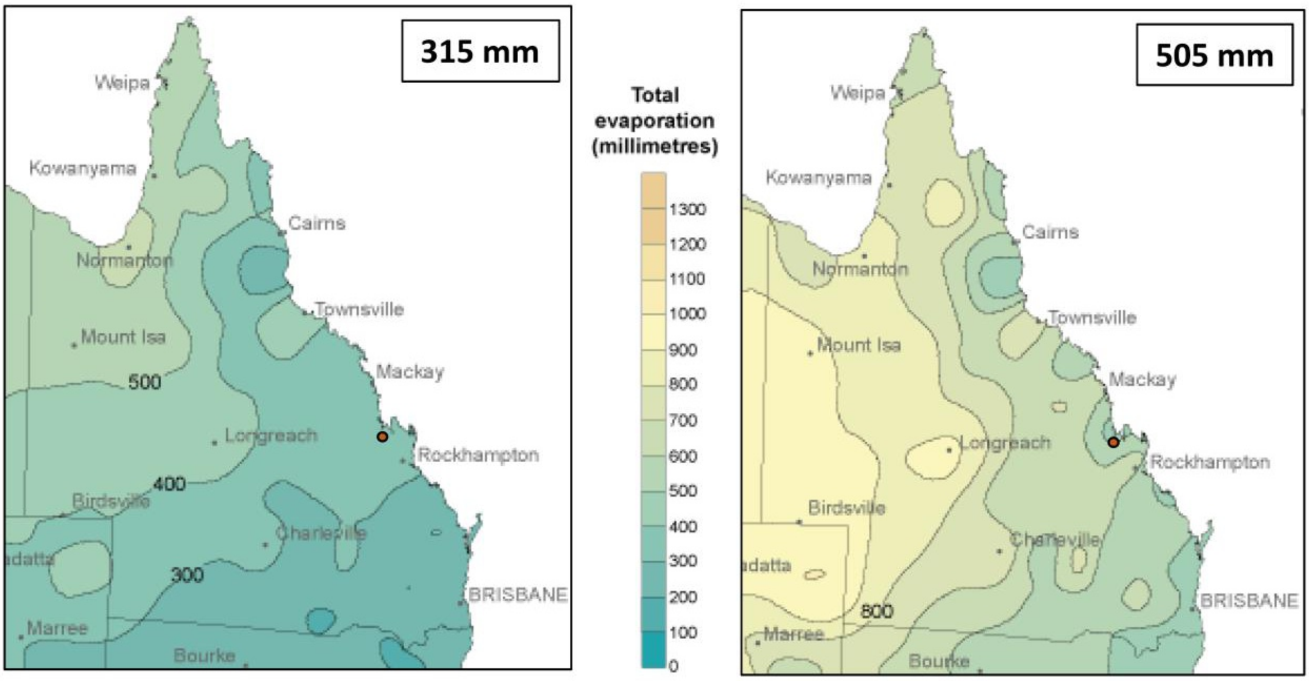
Bureau of Meteorology Weather Station Locations

[*with Dataset Annotations*]



Average Pan Evaporation (Summer)

Average Pan Evaporation (Autumn)



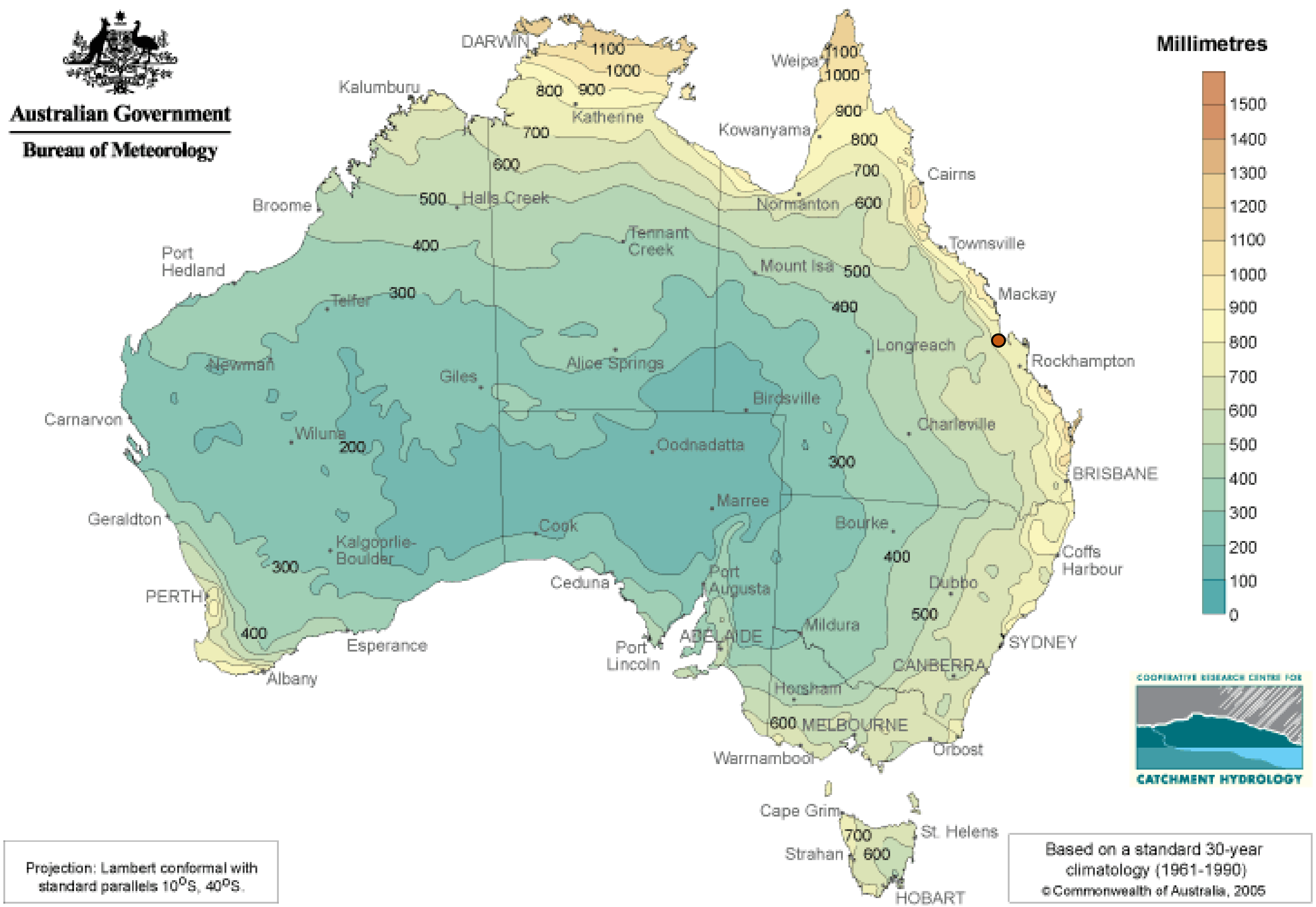
Average Pan Evaporation (Winter)

Average Pan Evaporation (Spring)

Figure 3-2

Average Pan Evaporation (Seasonal) [*with annotation*]

[*Source: After Australian Government Bureau of Meteorology, 2006*]



Projection: Lambert conformal with standard parallels 10°S, 40°S.

Based on a standard 30-year climatology (1961-1990)

Figure 3-3

Average Areal Actual Evapotranspiration (Annual) [*with annotation*]

[*Source: After Australian Government Bureau of Meteorology, 2005*]

Figure 3-4

Approximate Extent of LiDAR Survey Data Coverage (17 June 2011)

[*Source: Vekta Pty Ltd, 2011*]

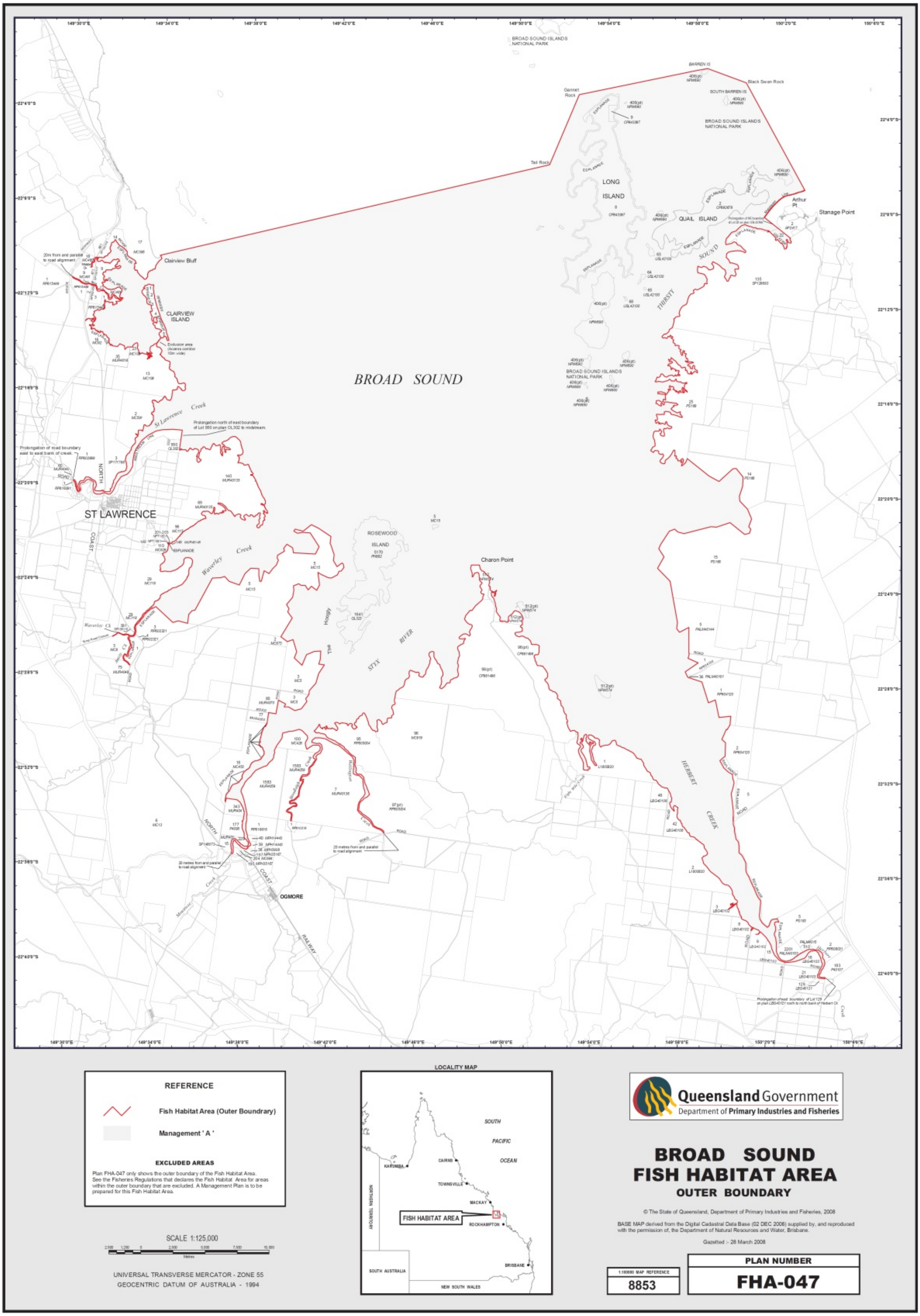


Figure 3-5

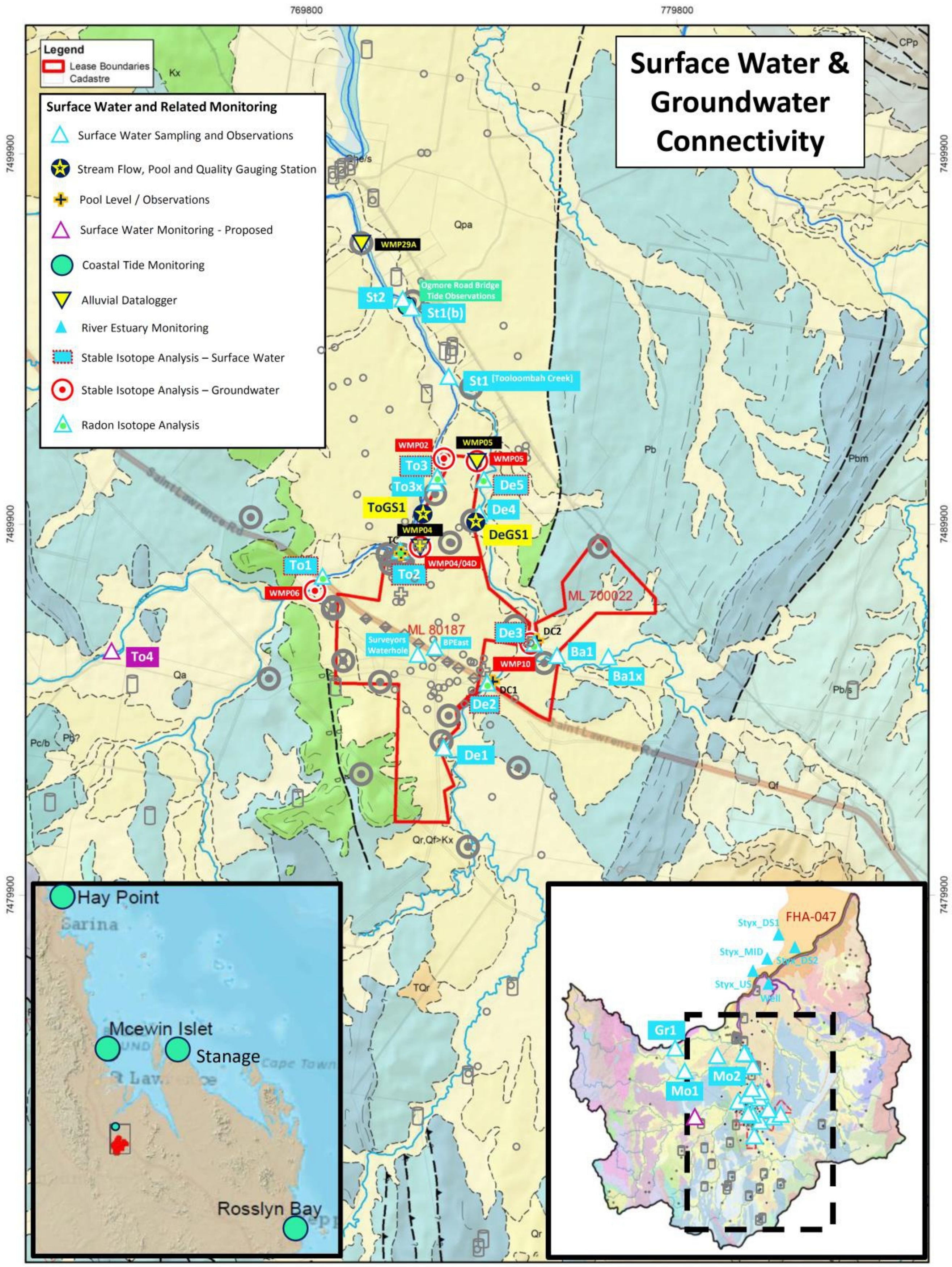
Broad Sound Fish Habitat Area (FHA-047)

[*Source: Qld Government Department of Primary Industries and Fisheries, 2008*]

Figure 3-6

Catchments and Sub-Catchments of the Styx River (Mouth) Catchment

[*Source: Base Map After QGIS OpenMap, 2019*]



CENTRAL QUEENSLAND
COAL PROJECT

Tenement Boundary: CQC 2019
Geological Mapping: DNRMW, 2006 (vector data DNRME 2018)

Figure 3-7

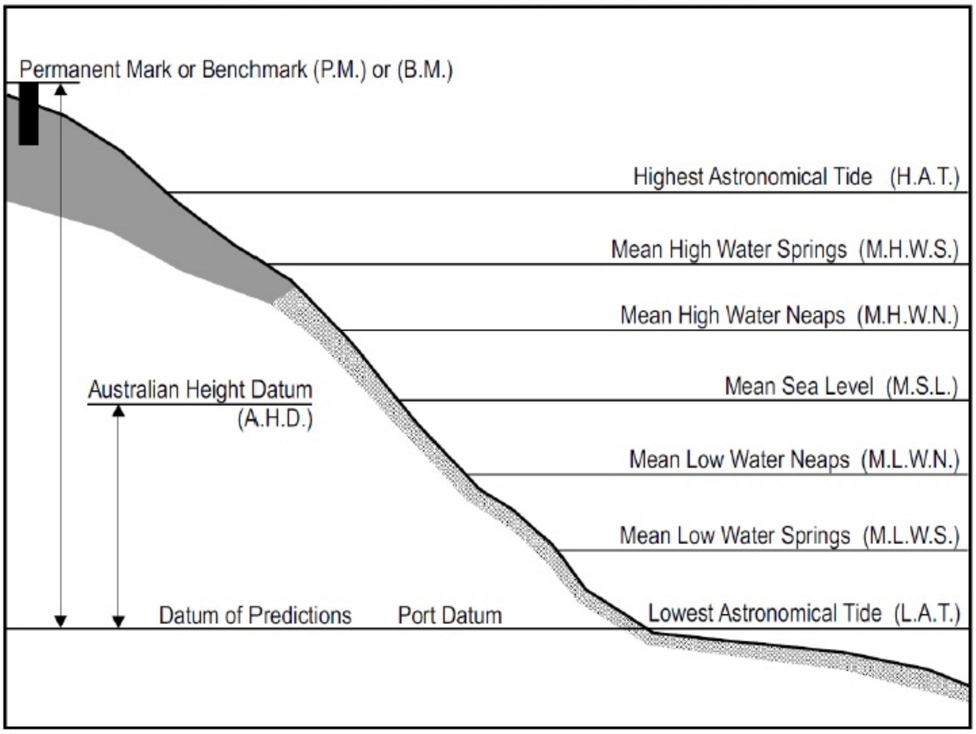
Surface Water Sampling Sites

[Source: CQCPL, 2020; ALS, 2011;2019; and CDM Smith, 2018]

Tidal datum epoch

The Queensland standard ports' semidiurnal and diurnal tidal planes were updated for the current tidal datum epoch 1992 – 2011, using the latest available tidal observations, prediction information and allowance for sea level rise. It is intended to maintain the standard port datum planes until an offical review highlights the need for an update to the epoch . The secondary place tidal planes have also been updated to match the new values adopted at the standard ports.

Guide to Semidiurnal Tidal Planes



Guide to Diurnal Tidal Planes

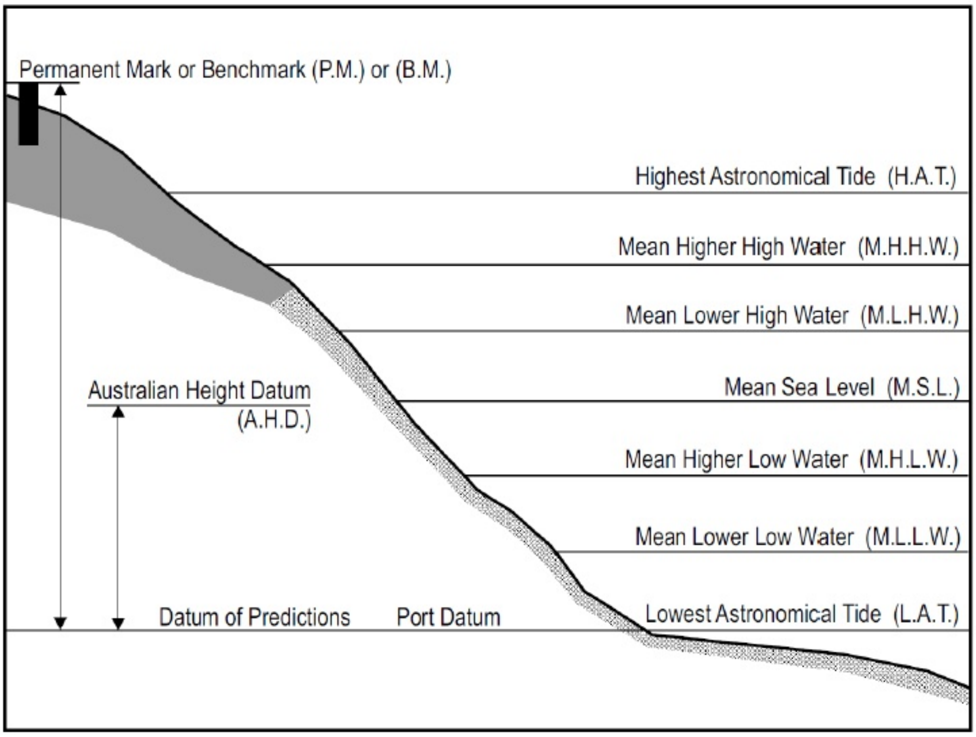


Figure 3-8

Guide to Tidal Planes

[*Source: Maritime Safety Queensland, 2019*]

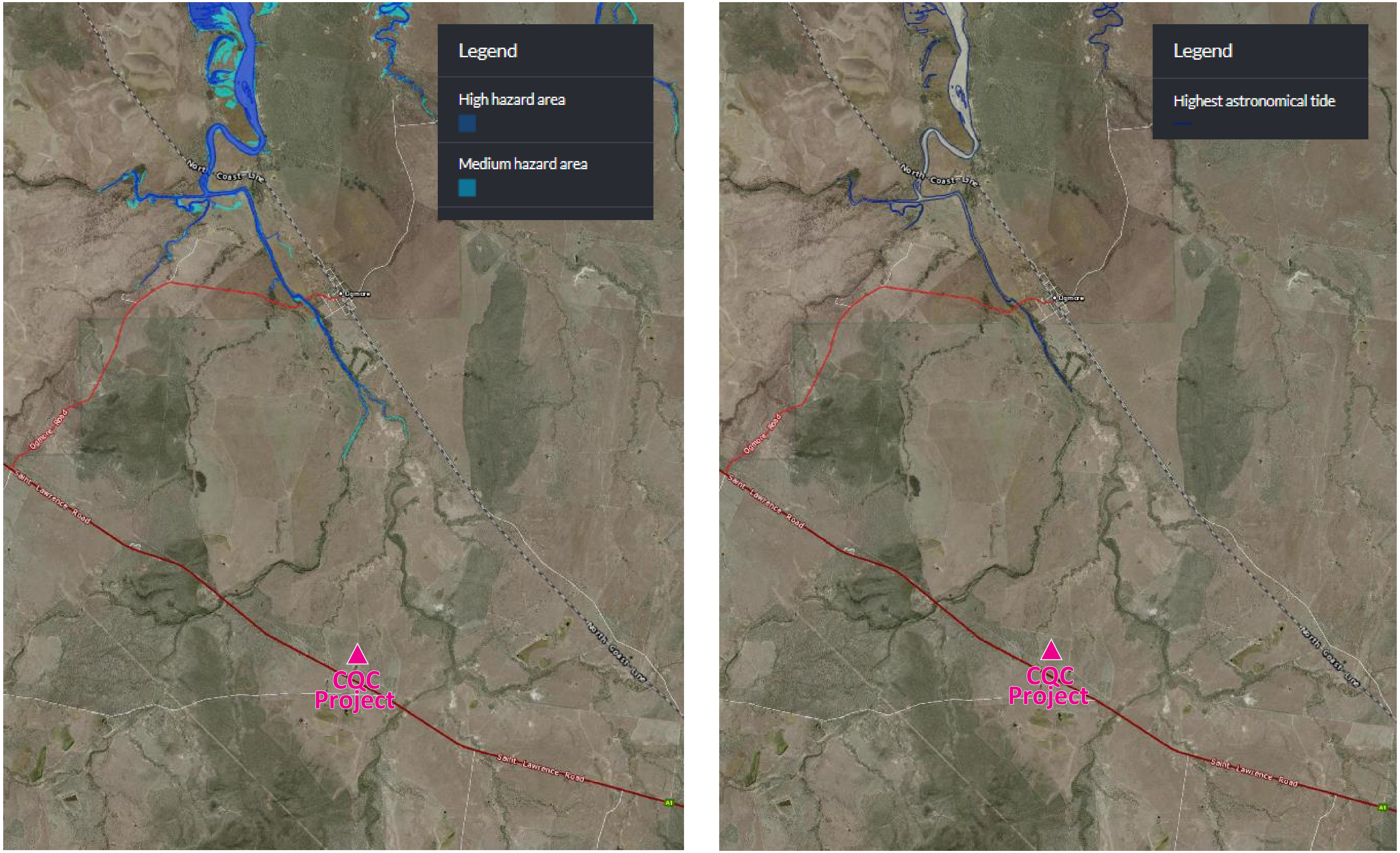


Figure 3-9

Storm Tide Hazard and Highest Astronomical Tide Mapping [*with annotation*]

[*Source: After Qld Globe, 2019*]

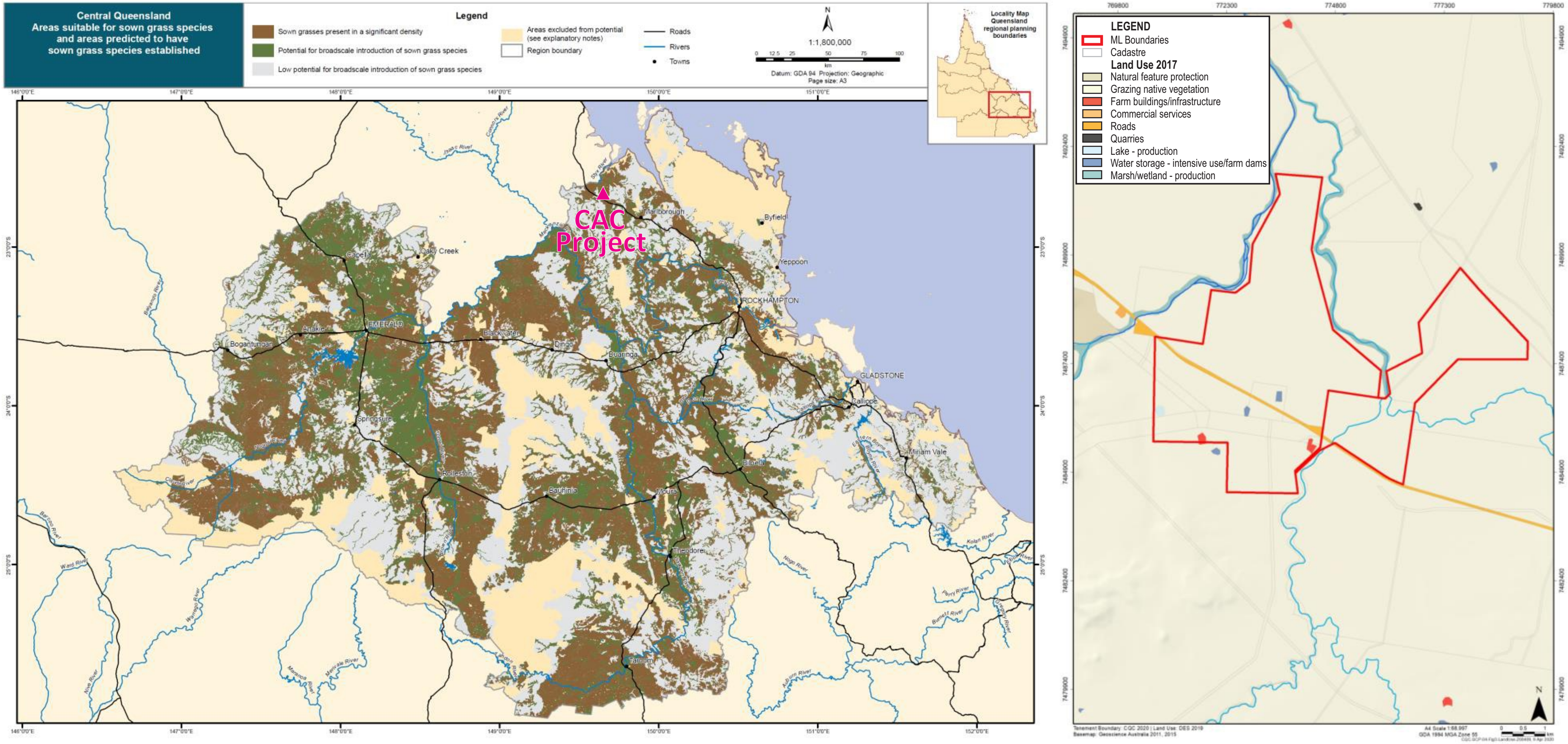


Figure 3-10

Queensland Agricultural Land Audit May 2013 - Central Queensland [*with annotation*] **and Relevant Land Use Information**

[*Source: CQCPL, 2020*]

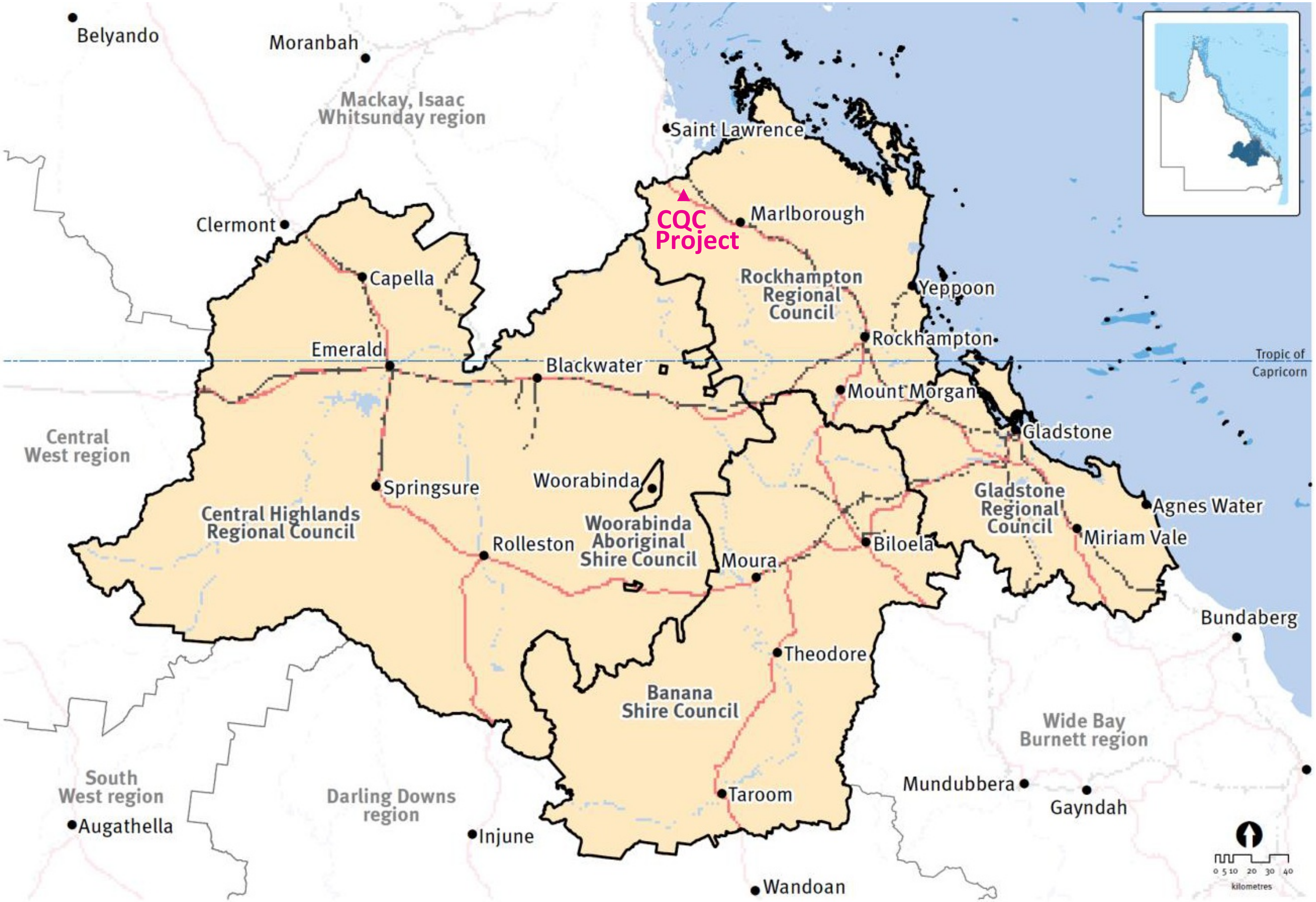


Figure 3-11

Central Queensland Regional Plan 2003 Map [*with annotation*]

[*Source: After Figure 5 in DSDIP, 2019*]

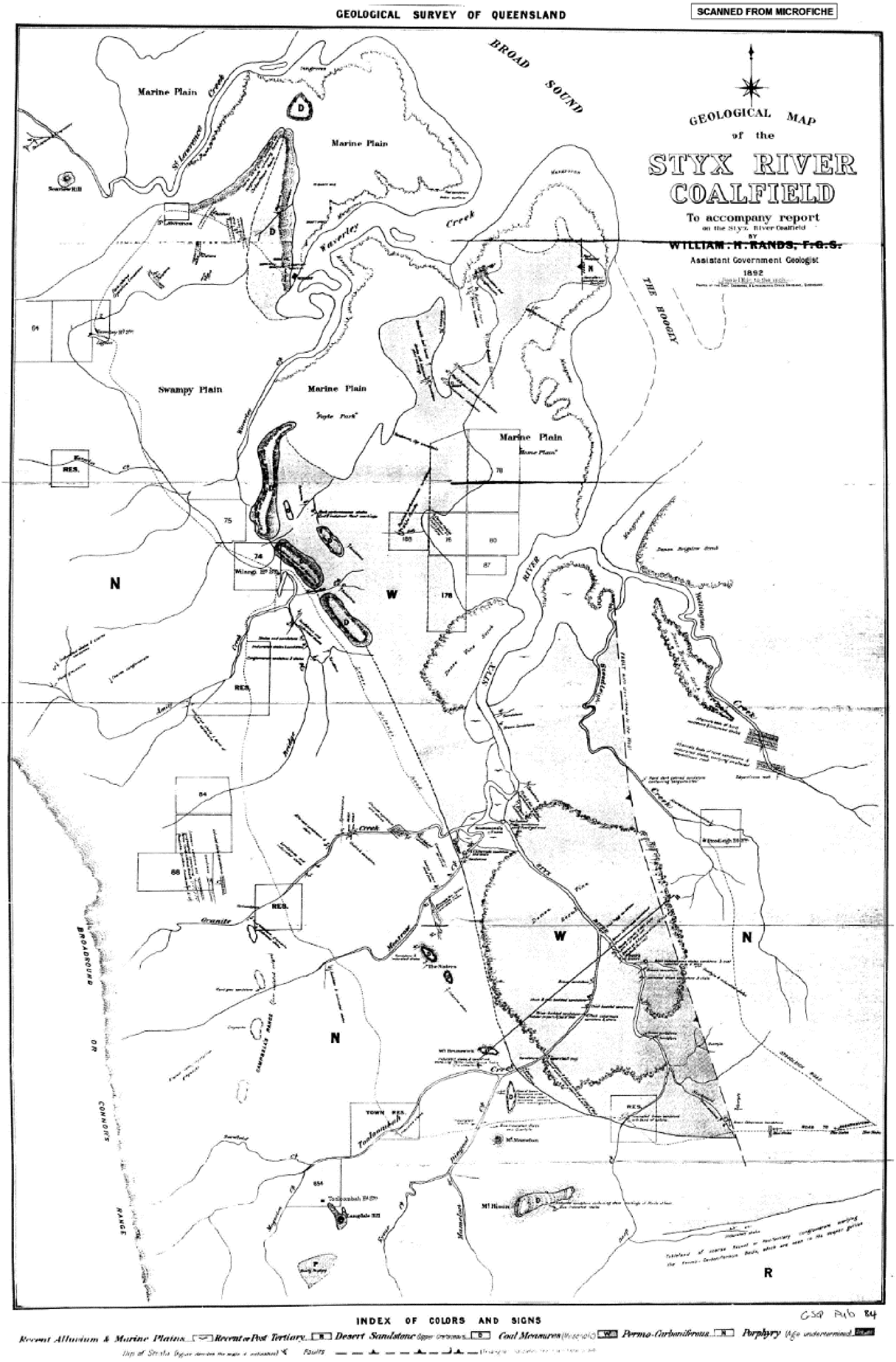


Figure 3-12

Styx River Coalfield - 1892 Map

[*Source: Geological Survey of Queensland (W.H. Rands, 1892)*]

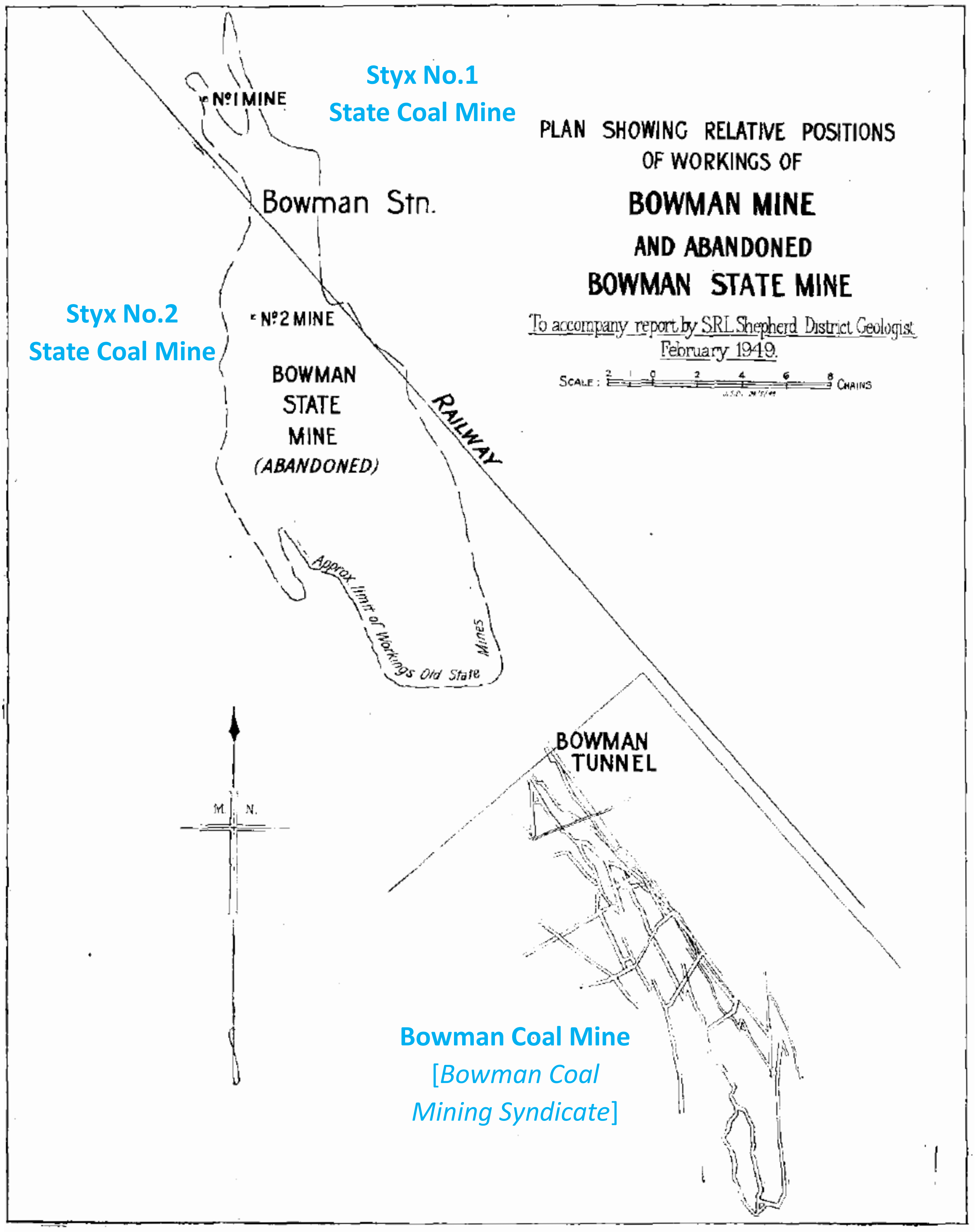


Figure 3-13

Styx No.1 and Styx No.2 State Coal Mine
(Relative to Bowman Coal Mine) [*with annotation*]

[*Source: SRL Shepherd, District Geologist in Queensland Government Mining Journal, 1949*]

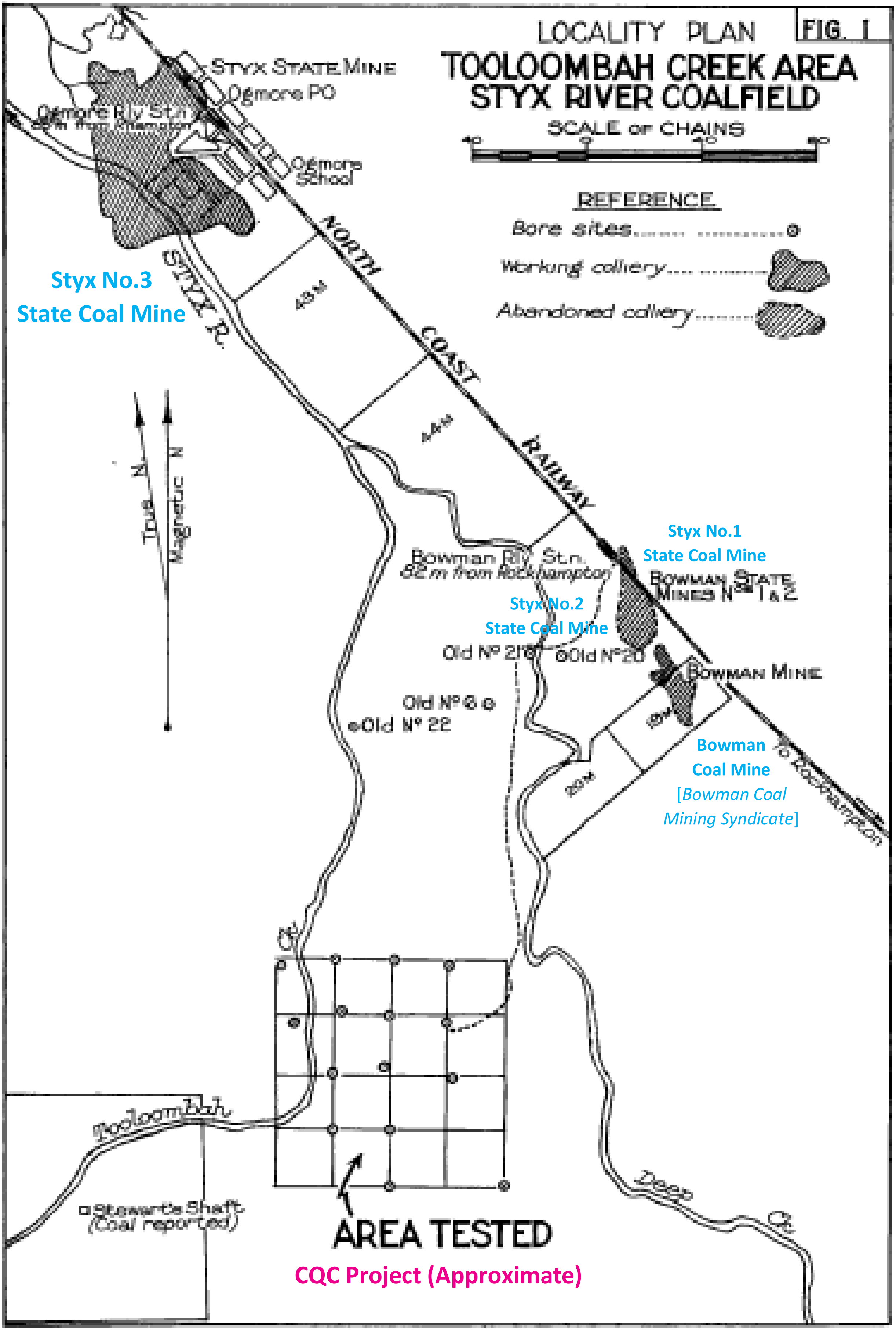
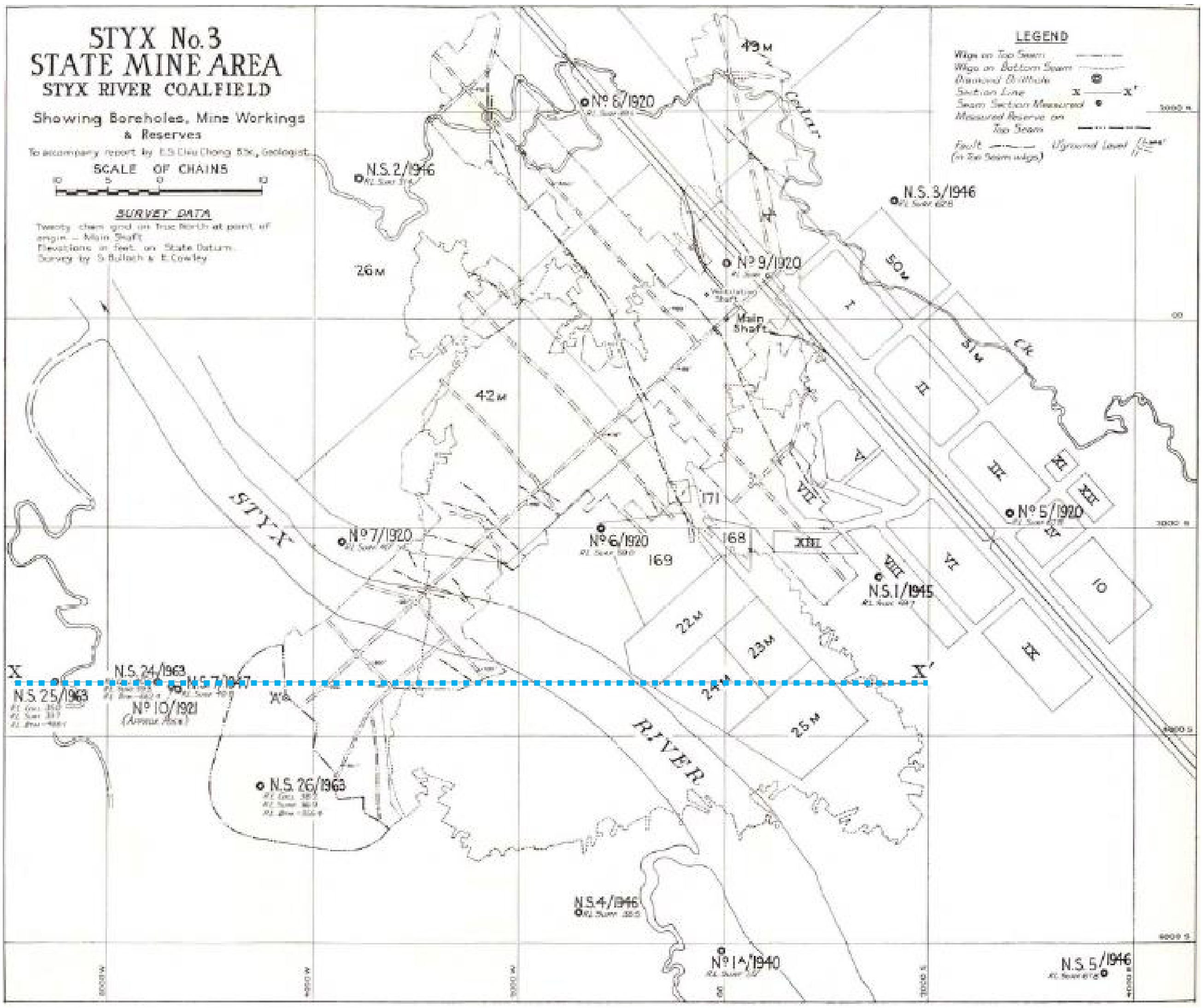


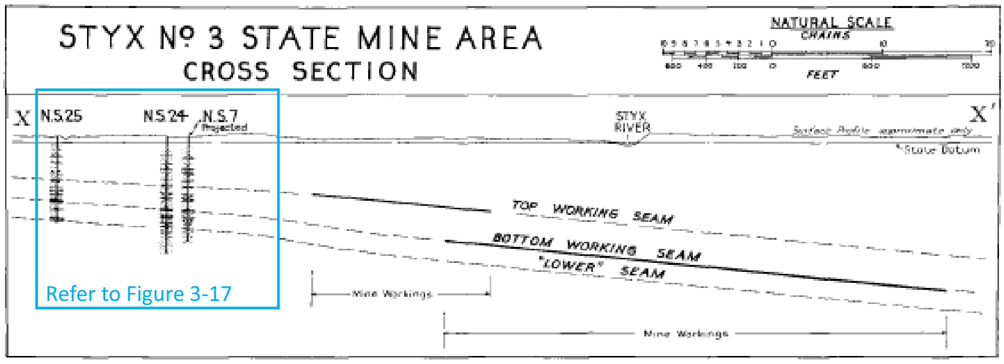
Figure 3-14

Styx No.3 State Coal Mine (Relative to Styx No.1 and Styx No. 2 State Coal Mine and Bowman Coal Mine) [*with annotation*]

[*Source: Plan copy provided by CQPL*]



[a] Boreholes, Mine Workings and Reserves at the Styx No.3 State Coal Mine [*with section annotation*]



[b] Cross-Section X-X' at Styx No.3 State Coal Mine [*with annotation*]

Figure 3-15

Styx No.3 State Coal Mine - Mine Workings and Cross Section

[*Source: Chong, 1964*]

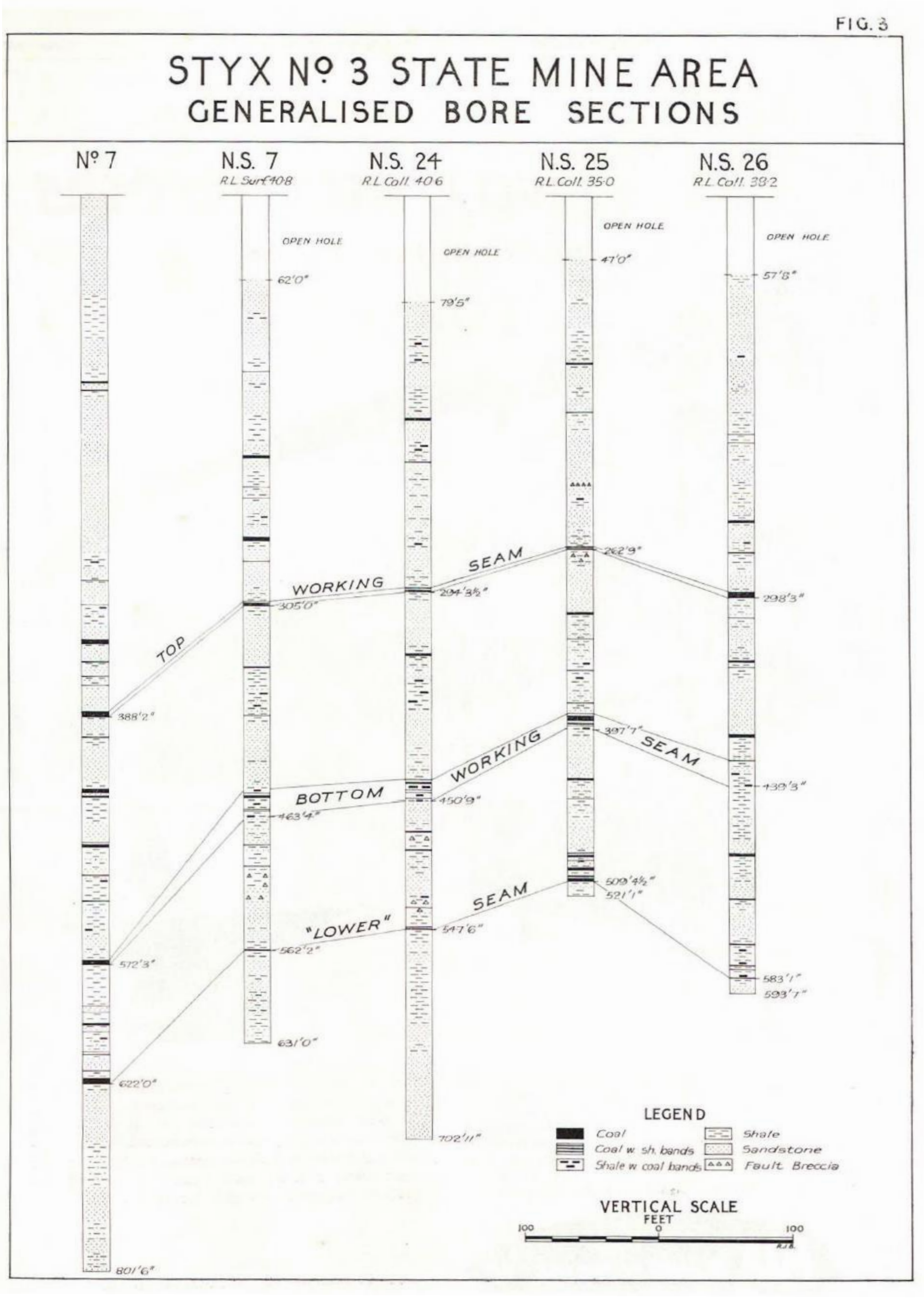


Figure 3-16

Styx No.3 State Coal Mine - Generalised Bore Sections

[*Source: Fig. 3 in Chong, 1964*]

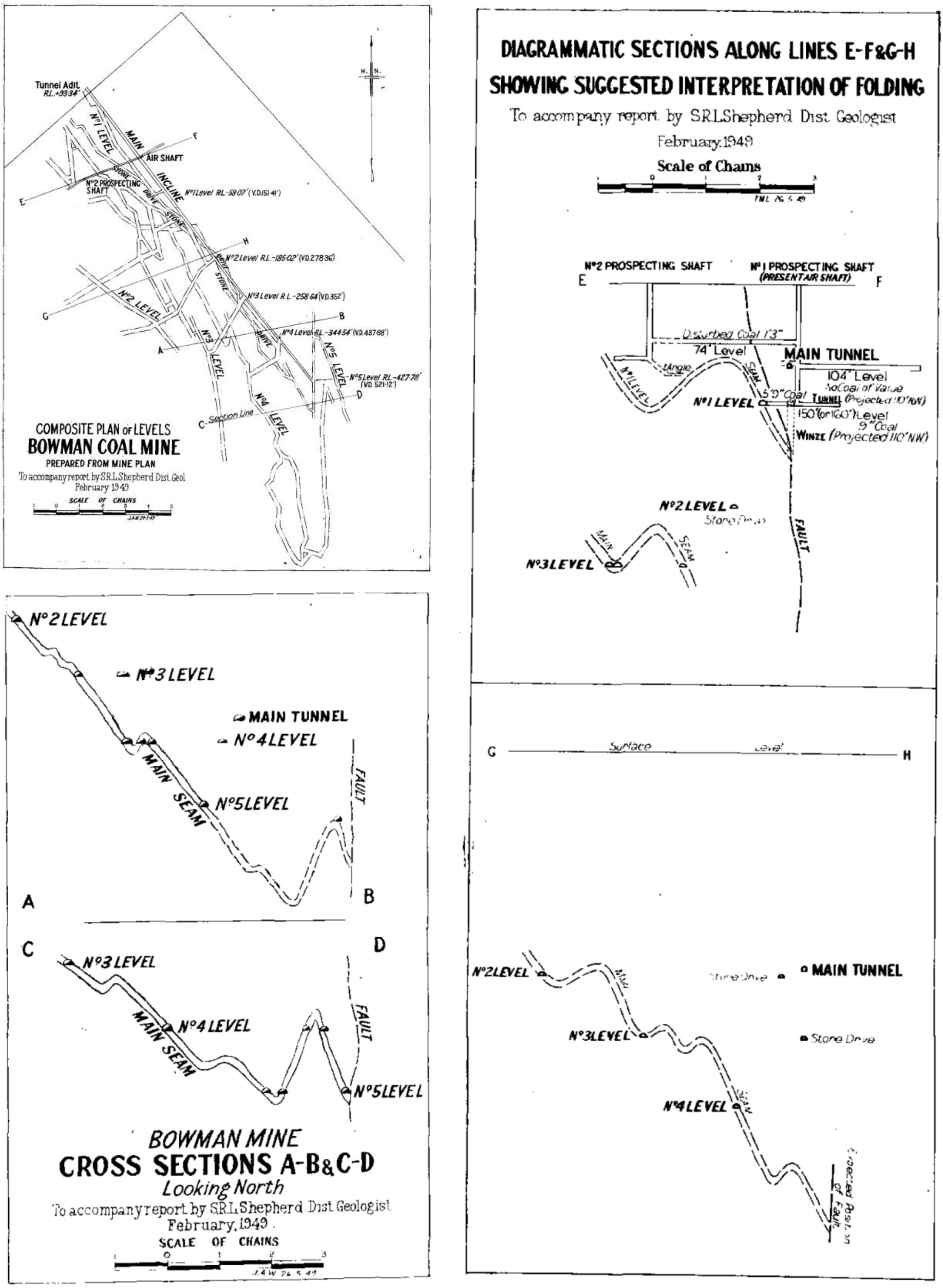


Figure 3-17

Bowman Coal Mine - Composite Plans and Diagrammatic Sections (1949)

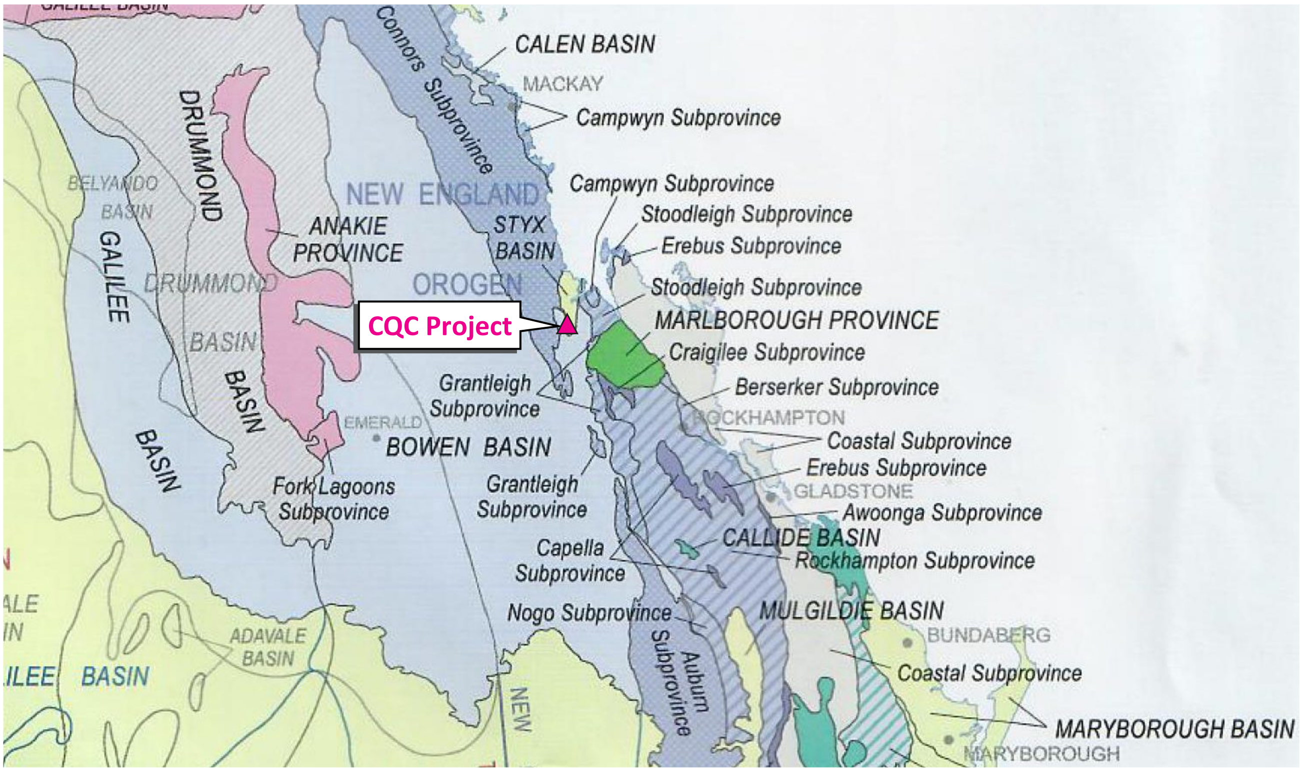
[*Source: SRL Shepherd, District Geologist in Queensland Government Mining Journal, 1949*]

Note: This map shows Great Barrier Reef Catchments that apply to the Map of Great Barrier Reef Wetland Protection Areas. Wetland protection areas under State Code 9 of the State Development Assessment Provisions are shown on the Map of Great Barrier Reef Wetland Protection Areas, as defined in the Environmental Protection Regulation 2019. The Map of Great Barrier Reef Wetland Protection Areas can be obtained at an allotment scale from www.des.qld.gov.au

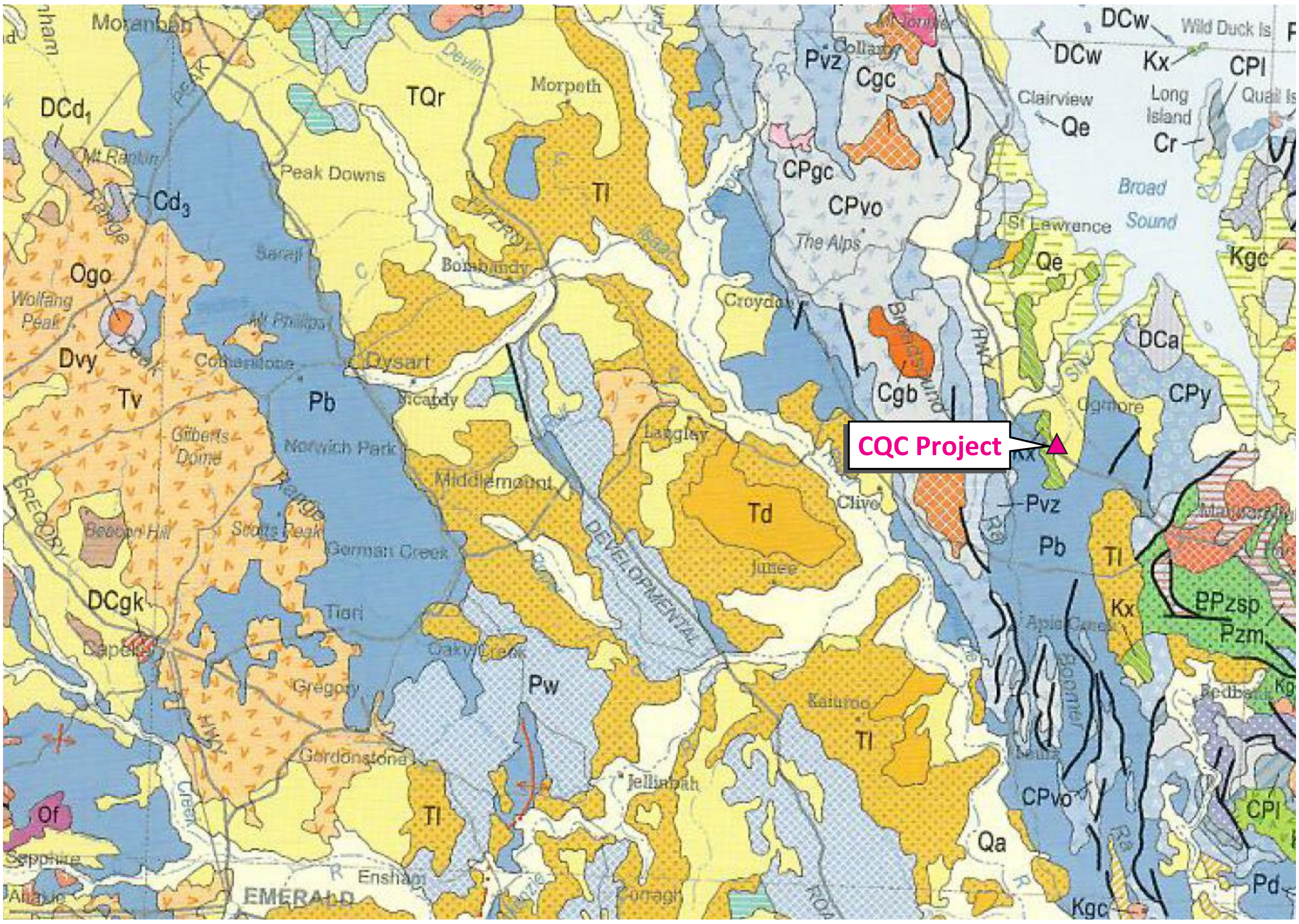
Figure 3-18

Great Barrier Reef River Catchments - Daintree to Fraser Island

[*Source: Qld Government, 2019*]



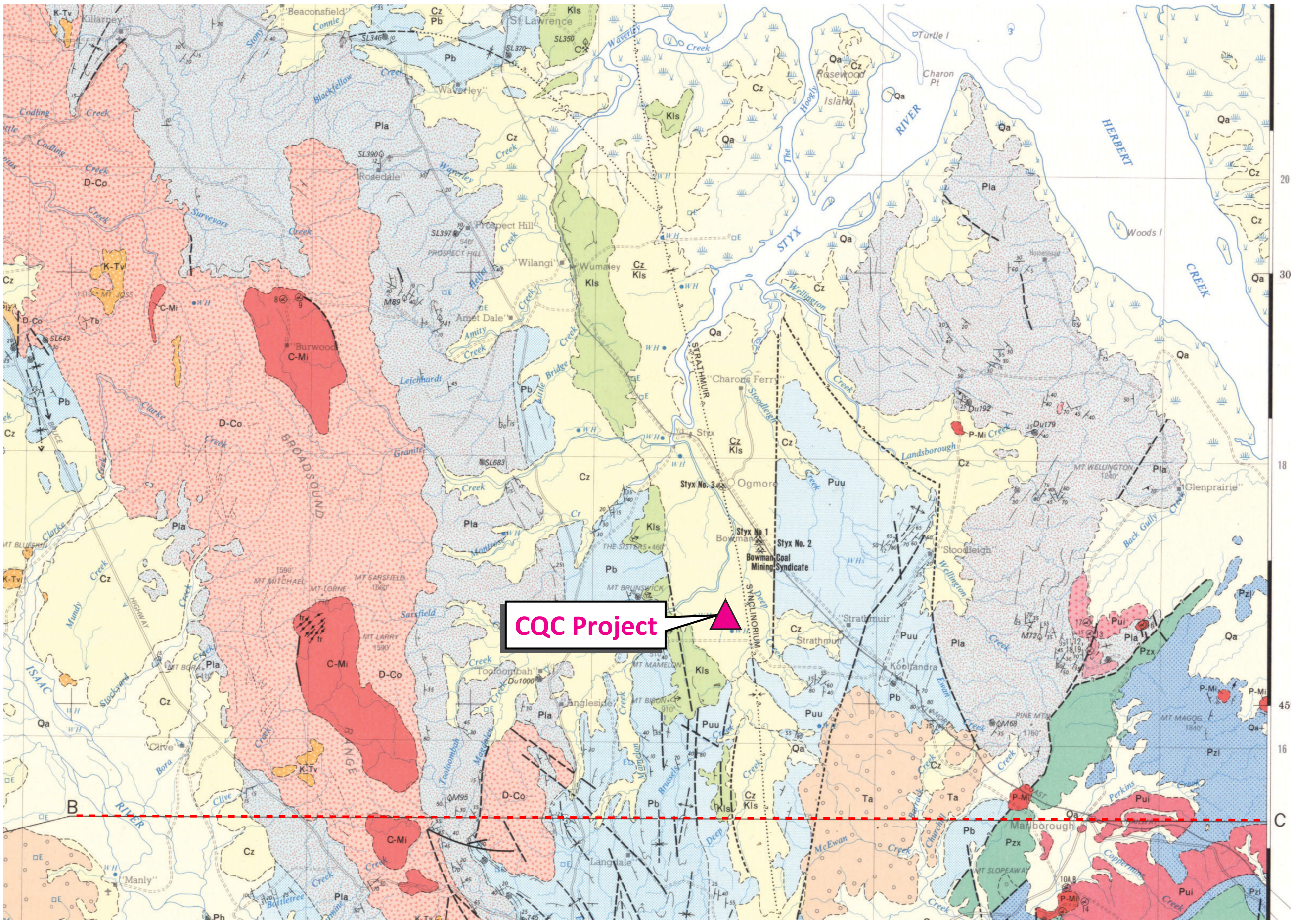
[a] Pre-Cenozoic Structural Framework [*excerpt with annotation*]
[*Source: After Geological Survey of Queensland, 2012*]



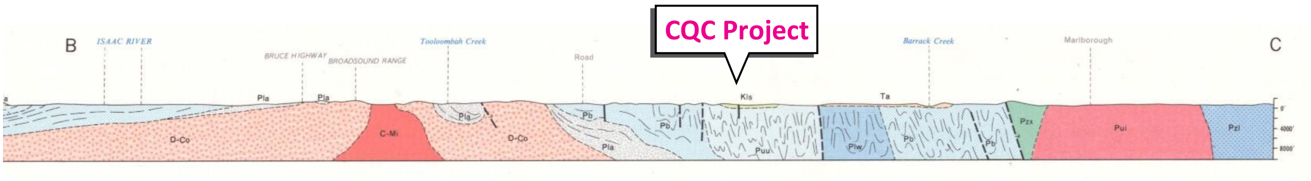
[b] Queensland Geology Scale 1:2,000,000 [*excerpt with annotation*]
[*Source: After Geological Survey of Queensland, 2012*]

Figure 4-1

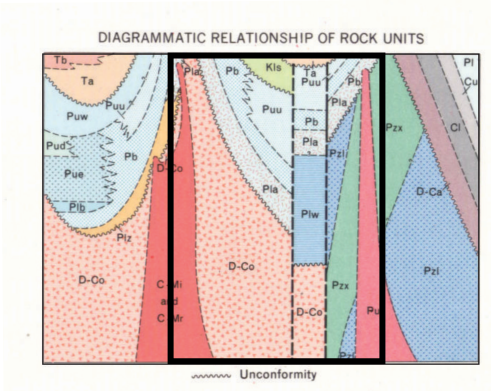
1:2,000,000 Scale Geological Series Mapping Across CQC Project



[a] 1:250,000 Scale Geological Series – St Lawrence Sheet SF/55-12



[b] Cross-Section B-C in 1: 250,000 Scale Geological Series – St Lawrence Sheet SF/55-12



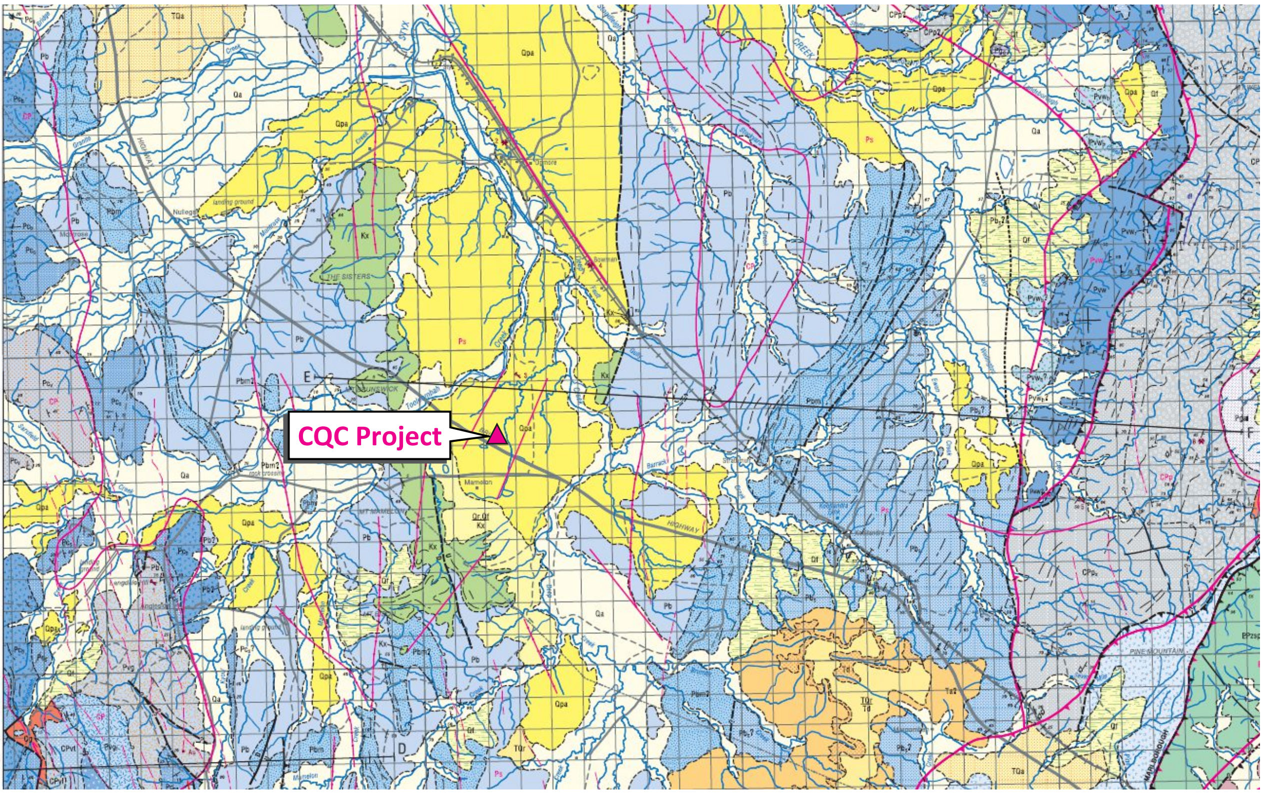
[c] Diagrammatic Relationship of Rock Units in 1: 250,000 Scale Geological Series – St Lawrence Sheet SF/55-12

Figure 4-2

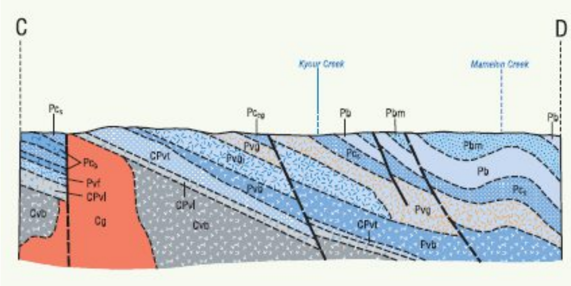
1:2,000,000 Scale Geological Series Mapping Across CQC Project

[excerpt with annotation]

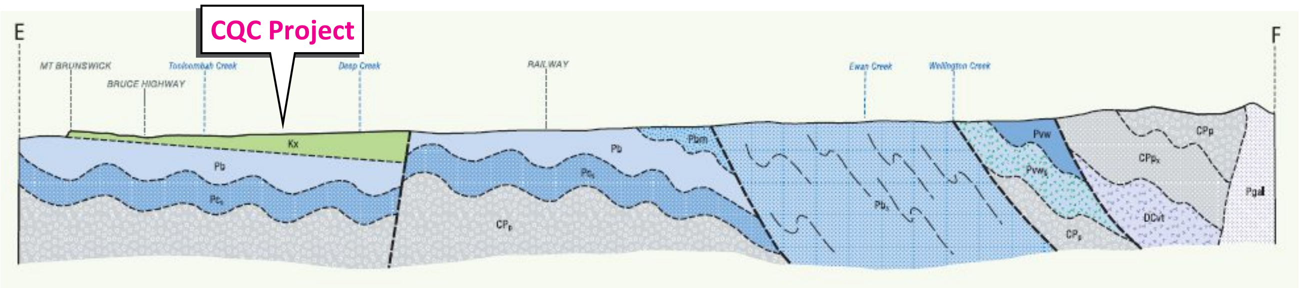
(http://scanned-maps.geoscience.gov.au/250dpi/sf5512.jpg)



[a] 1:100,000 Scale Geological Series Mapping Across CQC Project – Marlborough Sheet 8852
[*excerpt with annotation*] [*Source: After DNRMW, 2006*]



[b] Cross-Section C-D in 1:100,000 Scale Geological Series Mapping South-West of CQC Project – Marlborough Sheet 8852 [*Source: DNRMW, 2006*]



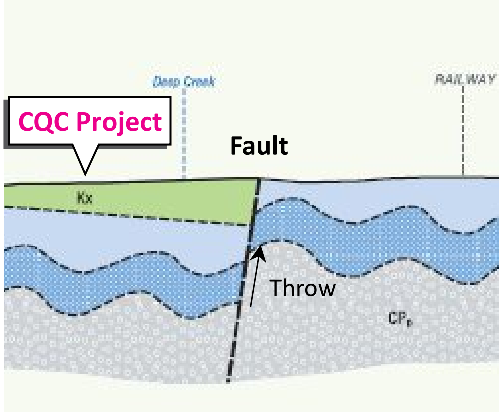
[c] Cross-Section E-F in 1:100,000 Scale Geological Series Mapping Across CQC Project – Marlborough Sheet 8852 [*with annotation*] [*Source: After DNRMW, 2006*]

Figure 4-3

1:100,000 Scale Geological Series Mapping Across CQC Project - Marlborough Sheet 8852

		QUATERNARY	
		Qhm	Mud and sandy mud; mangrove swamps
		Qhe_s	Sand, muddy sand, mud and minor gravel; estuarine channels and intertidal sand banks and flats
		Qhe_m	Mud, sandy mud, muddy sand and minor gravel; estuarine channels and banks, supratidal flats and coastal grasslands
		Qa	Clay, silt, sand, gravel: flood plain alluvium
		Qf	Sand, gravel, clay: floodout sheets and small fans
		Qpa	Sand, mud and gravel: alluvium on higher terraces, commonly with 'melon holes'
		Qr	Clay, silt, sand, gravel and soil: colluvial and residual deposits
		TERTIARY - QUATERNARY	
		TQa	Clay, silt, sand and gravel: high-level alluvium and colluvium
		TQf	Sand, gravel, clay: floodout sheets and small fans
		TQr	Clay, silt, sand, gravel and soil: colluvial and residual deposits
		TERTIARY	
		Td	Indurated and ferruginised top of deep weathering profiles, locally including ferricrete
		Ta	Sandy claystone, clayey sandstone, minor gravel beds: old alluvium; locally some interbedded basalt
	Herbert Creek beds	Th	Lacustrine mudstone, shale, oil shale, sandstone, lignite; non-magnetic domain
		CRETACEOUS	
	Styx Coal Measures	Kx	Quartzose sandstone, mudstone, conglomerate and coal
		LATE PERMIAN - EARLY TRIASSIC	
		PRg_b	Grey, fine to coarse-grained, equigranular to porphyritic gabbro, hornblende diorite and quartz diorite to biotite-hornblende quartz monzodiorite; strong magnetic domain
	Racecourse Creek Gabbro	PRgrc	Dark grey to black, coarse to very coarse-grained hornblende gabbro
		PERMIAN	
		Ps	Sandstone, mudstone, conglomerate; weak magnetic domain
		LATE PERMIAN	
		Pg_b	Gabbro, diorite
		Pg_d	Diorite and quartz diorite, commonly altered
		Pg_s	Pegmatitic to coarse-grained tourmaline-garnet-muscovite granite
	Og Syenite	Pgog	Coarse-grained biotite syenite
	Magog Gabbro	Pgmg	Coarse to very coarse-grained hornblende gabbro with minor hornblende monzonite
	Cleethorpes Granodiorite	Pgct	Grey, medium-grained hornblende-biotite granodiorite; moderate magnetic domain
	Aitken Creek Gabbro	Pgal	Medium to coarse-grained biotite-hornblende-pyroxene gabbro; strong magnetic domain
	Copperville Granodiorite	Pgcv	Grey, medium-grained biotite-hornblende granodiorite, biotite-hornblende quartz diorite and porphyritic microdiorite; moderate magnetic domain
Back Creek Group	Boomer Formation	Pbm	Lithic sandstone, siltstone, mudstone, rare poorly-sorted conglomerate and pebbly to cobbly siltstone and mudstone
Back Creek Group		Pb_s	Mudstone, siltstone and lithic sandstone
Back Creek Group		Pb	Predominantly massive, cleaved mudstone and siltstone (commonly with concretions), minor lithic sandstone
		EARLY PERMIAN	
Back Creek Group		Pb_c	Lithic sandstone, calcareous siltstone and limestone; locally fossiliferous
	Wongrabry beds	Pvw	Predominantly volcanolithic sandstone and polymictic conglomerate; subordinate basalt or andesite and rhyolite; rare limestone and coquinite; weak to moderate magnetic domain
		Pvw_b	Aphyric to slightly porphyritic basalt, locally amygdaloidal
		Pvw_r	Flow banded to massive, aphyric to porphyritic rhyolite or trachyte
	Rookwood Volcanics	Pvr_b	Basaltic pillow lava and breccia, minor chert, sandstone, siltstone; some dolerite sills or dykes; weak to moderate magnetic domain
Lizzie Creek Volcanic Group	Carmila beds	Pc_v	Rhyolitic to dacitic volcaniclastic rocks (poorly sorted, volcanic sandstone and breccia and ignimbrite); minor altered basalt
Lizzie Creek Volcanic Group		Pc_b	Altered (uralitised and carbonatised) locally amygdaloidal, aphyric basalt
Lizzie Creek Volcanic Group		Pc_{cg}	Polymictic, pebble to cobble conglomerate
Lizzie Creek Volcanic Group		Pc_s	Siltstone and mudstone, volcanolithic sandstone and conglomerate and minor altered basalt
Lizzie Creek Volcanic Group	Langdale Hill Rhyolite	Pvg	Greenish grey to grey, crystal-rich (feldspar, quartz and biotite) rhyolitic ignimbrite, locally containing lithic clasts and flamme; some rhyolite flows
Lizzie Creek Volcanic Group		Pvg_r	Grey, sparsely feldspar-phyric, commonly autobrecciated rhyolite
Lizzie Creek Volcanic Group	Mount Buffalo Rhyolite	Pvf	Felsic (mainly rhyolitic) volcaniclastic sandstone, conglomerate, breccia and siltstone (tuff); minor crystal-rich to crystal-poor and lithic-rich to lithic-poor rhyolitic ignimbrite; local rhyolite flows (Section and Rock Relationship Diagram)
Lizzie Creek Volcanic Group / Mount Benmore Volcanics	Cerberus Rhyolite Member	Pvbc	Grey, moderately crystal-rich to crystal-rich (feldspar and minor quartz), lithic rich rhyolitic to dacitic ignimbrite
Lizzie Creek Volcanic Group / Mount Benmore Volcanics		Pvb	Basalt to basaltic andesite (commonly autoclastic), volcaniclastic sandstone and rudite; minor felsic lava and volcaniclastics
		LATE CARBONIFEROUS - EARLY PERMIAN	
Lizzie Creek Volcanic Group	Tartrus Rhyolite	CPvt	Grey, crystal-rich (feldspar and subordinate to rare quartz) rhyolitic ignimbrite
	Leura Volcanics	CPvl	Trachyandesite to dacite lava, dacitic to rhyolitic ignimbrite and volcaniclastic sandstone, conglomerate and siltstone; local basal conglomerate
	Glenprairie beds	CPp	Mainly medium to very coarse-grained, moderately to well-sorted feldspatholithic sandstone and conglomerate containing mainly felsic volcanic clasts; subordinate mudstone and siltstone; local felsic volcaniclastic rocks including crystal-rich ignimbrite; weak magnetic domain
		CPp_x	Mainly fine to coarse-grained feldspatholithic sandstone and minor granule conglomerate, mudstone and siltstone; local felsic volcaniclastic rocks
	Lorray Formation	CPl	Bryozoan-rich mudstone, fossiliferous siltstone, sandstone, granite-rich, quartz-bearing, polymictic conglomerate and subordinate crinoid-rich limestone
		CARBONIFEROUS - EARLY PERMIAN	
		CP	Basalt to rhyolite flows and volcaniclastic rocks and some granitoids; moderate to strong magnetic domain
		LATE CARBONIFEROUS	
		Cg	Granite, granodiorite, microgranite
	Broadsound Range Rhyolite	Cvb	Crystal-rich (feldspar and locally quartz), generally lithic-poor, locally flamme-bearing, rhyolitic ignimbrite; aphyric to sparsely porphyritic rhyolite flows and high-level intrusives
		LATE DEVONIAN - EARLY CARBONIFEROUS	
	Tanderra Volcanics	DCvt	Andesitic and basaltic lava and moderately to poorly-sorted volcaniclastic sandstone and conglomerate; minor dacitic lava and tuff; strong magnetic domain
		NEOPROTEROZOIC - PALAEOZOIC	
Marlborough Metamorphics		Pzm_m	Muscovite-biotite gneiss and schist, cordierite-andalusite schist, micaceous quartzite, chlorite schist, muscovite-biotite orthogneiss (mylonitised granite) and amphibolite; mostly weak magnetic domain with some strong magnetic linear features
Marlborough Metamorphics	Nob Creek Amphibolite	Pzm_n	Fine to medium-grained schistose amphibolite interbedded with minor quartz-mica-feldspar schist; minor stratiform massive sulphide
	Princhester Serpentinite	ЄPzsp	Sheared serpentinite, serpentinised harzburgite and minor dunite; minor lherzolite, pyroxenite, altered gabbro and dolerite, chromitite; very strong magnetic domain
		$ЄPzsp_s$	Sheared serpentinite surrounding blocks of metasomatically altered gabbro, actinolite, minor unsheared serpentinite and quartzite

[d] 1:100,000 Scale Geological Series – Marlborough Sheet 8852 – Legend [*excerpt*] [*Source: DNRMW, 2006*]



[e] 1:100,000 Scale Geological Series Mapping Across CQC Project – Marlborough Sheet 8852 – Mapped Fault Throw (Approximate) [*excerpt with annotation*] [*Source: After DNRMW, 2006*]

***Figure 4-3** (Continued)*

1:100,000 Scale Geological Series Mapping Across CQC Project - Marlborough Sheet 8852

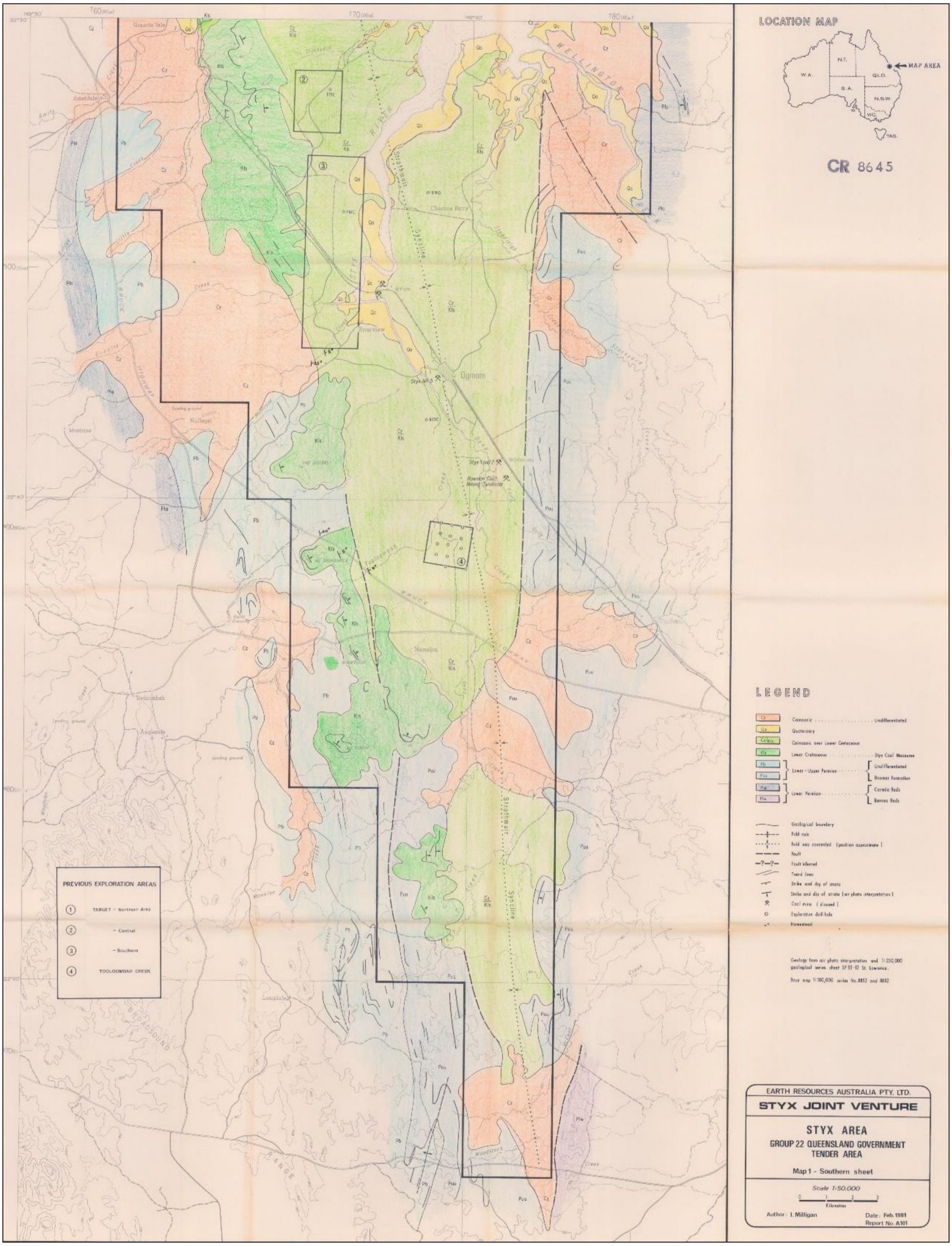


Figure 4-4

Geology from Field Mapping, Air Photo Interpretation and 1:250,000 Scale Geological Series - St Lawrence Sheet SF 55-12

[*Source: Earth Resources Australia Pty Ltd, 1981*]

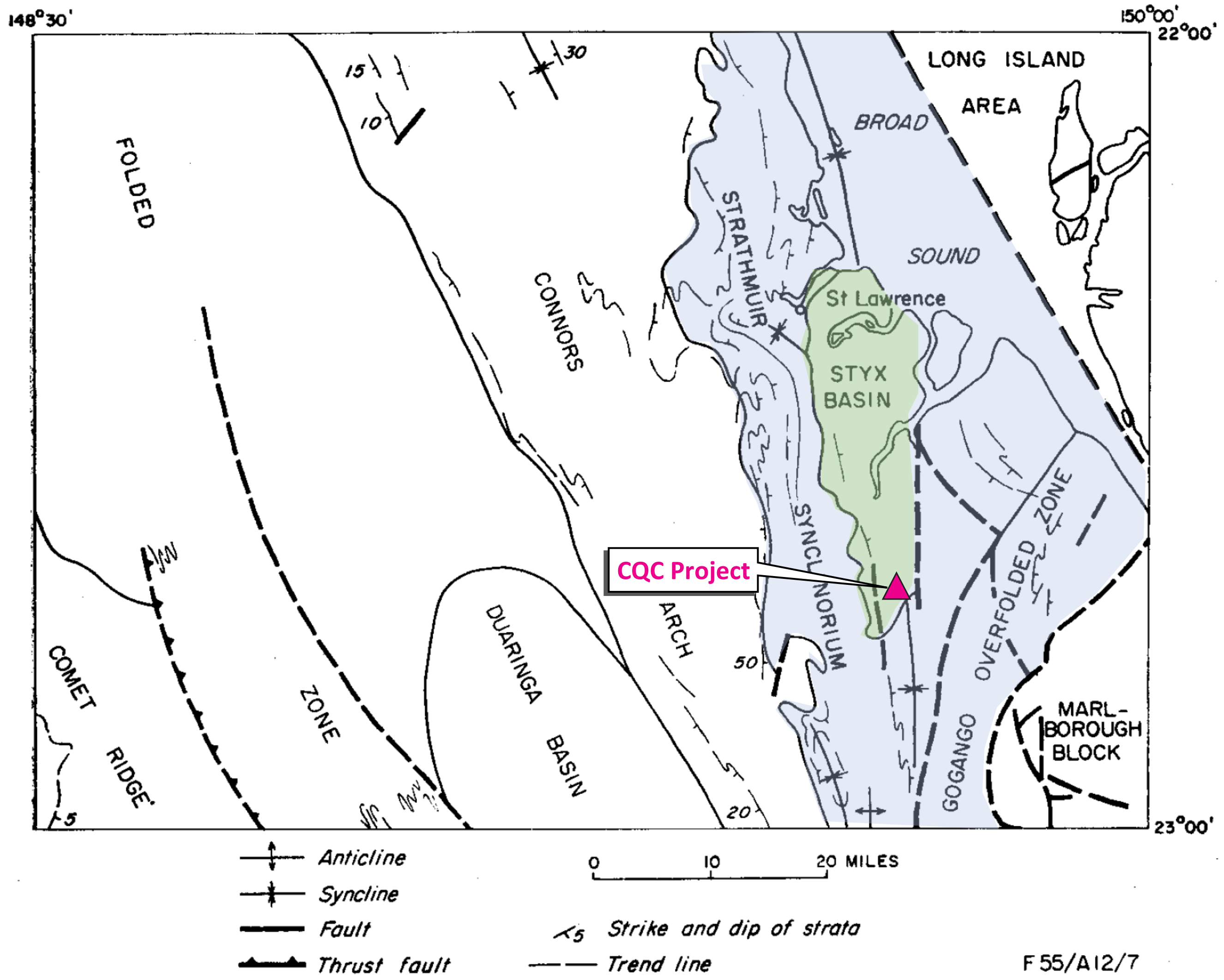
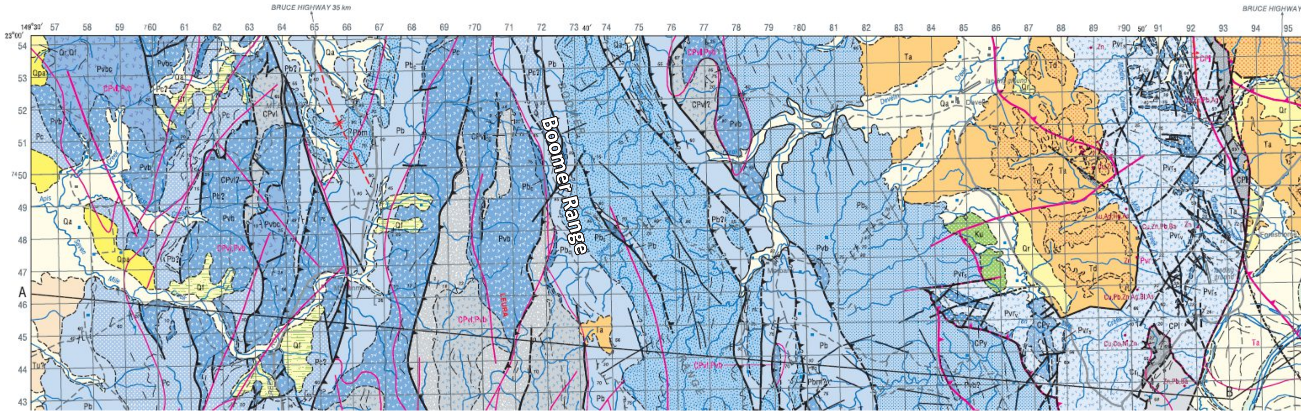


Fig. 3. Structural elements.

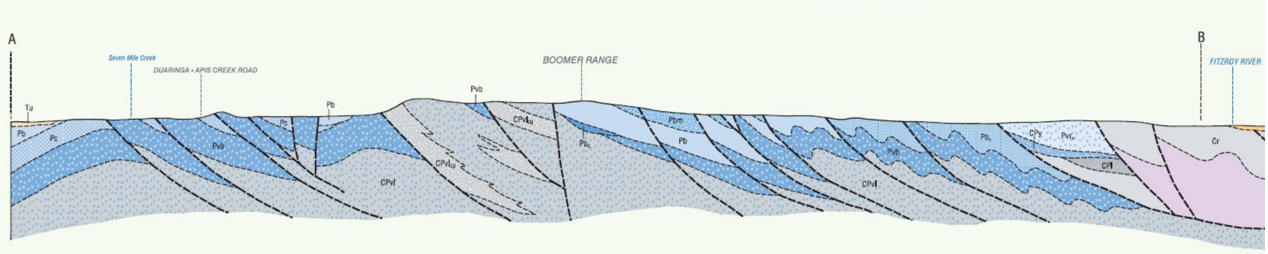
Figure 4-5

Structural Elements in the Styx Basin (Strathmuir Synclinorium and Gogango Overfolded Zone) [*with annotation*]

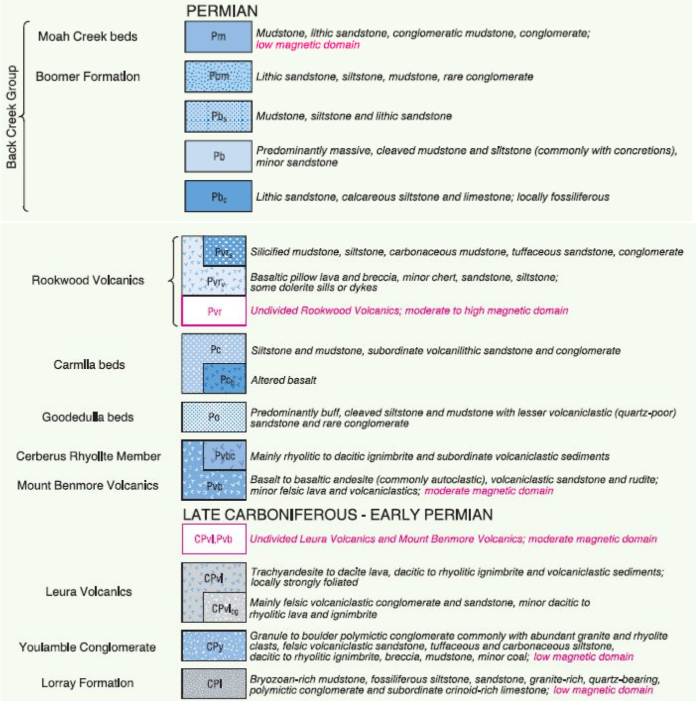
[*Source: Figure 3 in 1:250,000 Scale Geological Series Explanatory Notes (Malone, 1964)*]



[a] 1:100,000 Scale Geological Series Mapping of Boomer Formation South of CQC Project - Rookwood Sheet 8851 [*excerpt with annotation*] [*Source: DNRM, 2001*]



[b] Cross-Section A- B in 1:100,000 Scale Geological Series Mapping of Boomer Formation South of CQC Project - Rookwood Sheet 8851 [*excerpt*] [*Source: DNRM, 2001*]



			PERMIAN
Back Creek Group	Moah Creek beds	Pm	*Mudstone, lithic sandstone, conglomeratic mudstone, conglomerate; low magnetic domain*
	Boomer Formation	Pbm	*Lithic sandstone, siltstone, mudstone, rare conglomerate*
		Pb_s	*Mudstone, siltstone and lithic sandstone*
		Pb	*Predominantly massive, cleaved mudstone and siltstone (commonly with concretions), minor sandstone*
		Pb_c	*Lithic sandstone, calcareous siltstone and limestone; locally fossiliferous*
	Rookwood Volcanics	Pvr_s	*Silicified mudstone, siltstone, carbonaceous mudstone, tuffaceous sandstone, conglomerate*
		Pvr_v	*Basaltic pillow lava and breccia, minor chert, sandstone, siltstone; some dolerite sills or dykes*
		Pvr	*Undivided Rookwood Volcanics; moderate to high magnetic domain*
	Carmila beds	Pc	*Siltstone and mudstone, subordinate volcanilithic sandstone and conglomerate*
		Pc_b	*Altered basalt*
	Goodedulla beds	Pg	*Predominantly buff, cleaved siltstone and mudstone with lesser volcaniclastic (quartz-poor) sandstone and rare conglomerate*
	Cerberus Rhyolite Member	Pvbc	*Mainly rhyolitic to dacitic ignimbrite and subordinate volcaniclastic sediments*
	Mount Benmore Volcanics	Pvb	*Basalt to basaltic andesite (commonly autoclastic), volcaniclastic sandstone and rudite; minor felsic lava and volcaniclastics; moderate magnetic domain*
			LATE CARBONIFEROUS - EARLY PERMIAN
		CPvl,Pvb	*Undivided Leura Volcanics and Mount Benmore Volcanics; moderate magnetic domain*
	Leura Volcanics	CPvl	*Trachyandesite to dacite lava, dacitic to rhyolitic ignimbrite and volcaniclastic sediments; locally strongly foliated*
		$CPvl_{cg}$	*Mainly felsic volcaniclastic conglomerate and sandstone, minor dacitic to rhyolitic lava and ignimbrite*
	Youlamble Conglomerate	CPy	*Granule to boulder polymictic conglomerate commonly with abundant granite and rhyolite clasts, felsic volcaniclastic sandstone, tuffaceous and carbonaceous siltstone, dacitic to rhyolitic ignimbrite, breccia, mudstone, minor coal; low magnetic domain*
	Lorray Formation	CPl	*Bryozoan-rich mudstone, fossiliferous siltstone, sandstone, granite-rich, quartz-bearing, polymictic conglomerate and subordinate crinoid-rich limestone; low magnetic domain*

[c] 1:100,000 Scale Geological Series Mapping of Boomer Formation South of CQC Project - Rookwood Sheet 8851 Legend (Permian - Late Carboniferous) [*excerpt*] [*Source: DNRM, 2001*]

Figure 4-6

1:100,000 Scale Geological Series Mapping of Boomer Formation South of CQC Project - Rookwood Sheet 8851

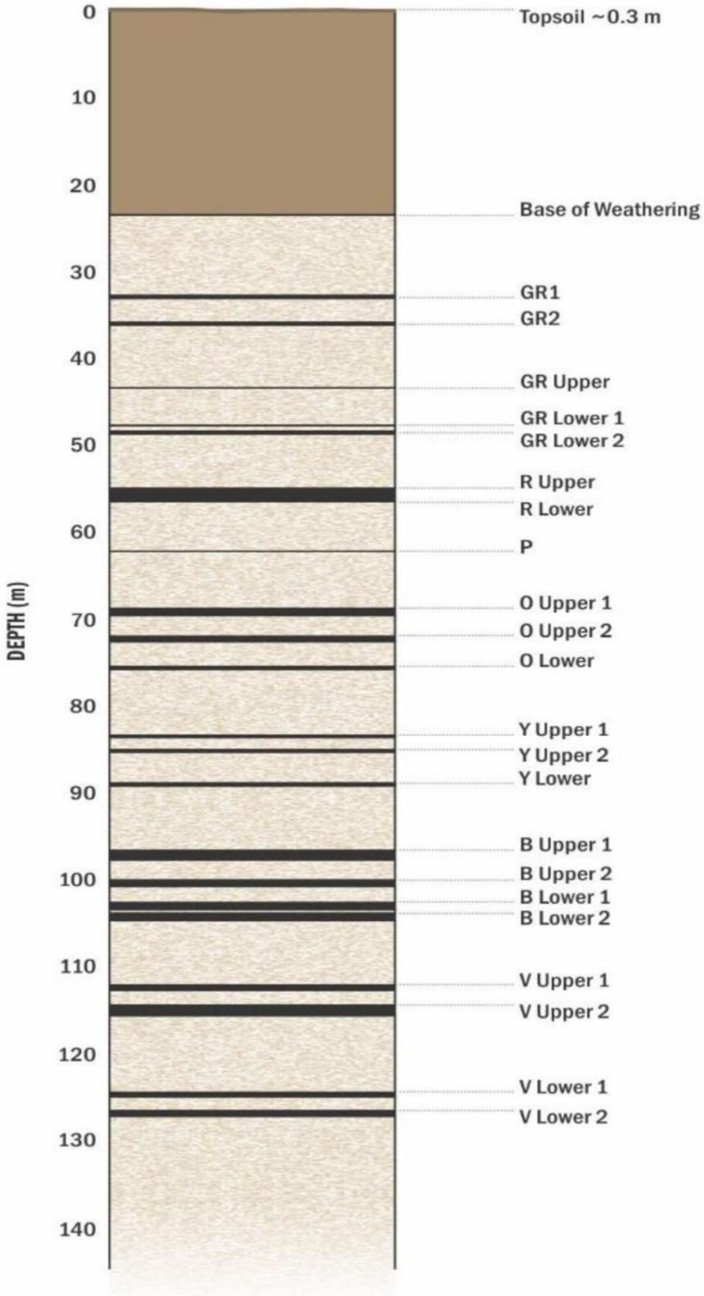


Figure 4-7

Schematic Stratigraphic Section in the CQC Project Area

[*Source:Figure 5-6 in CDM Smith, 2018*]

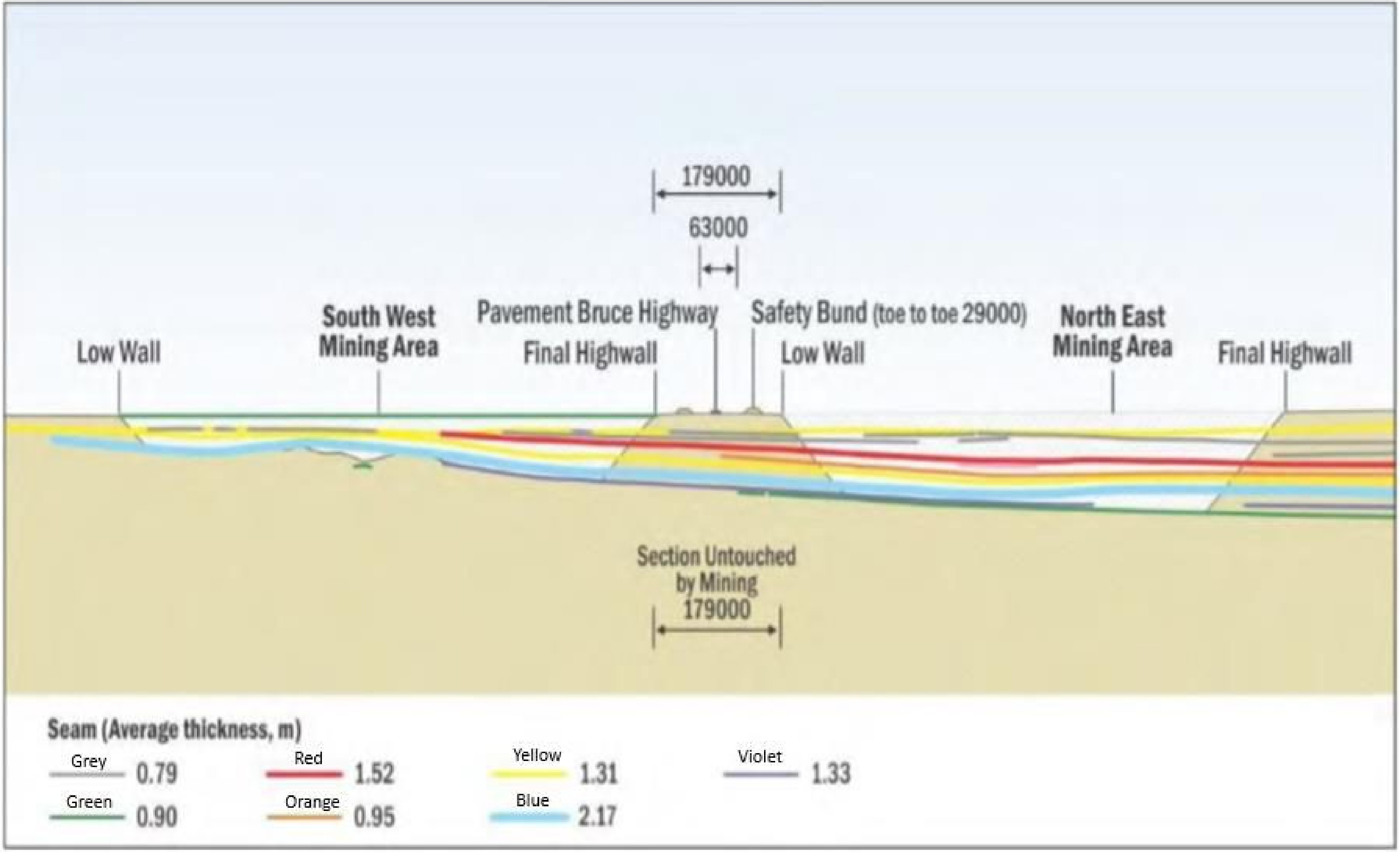


Figure 4-8

Indicative Geological Cross-Section within CQC Project Open Cut Extent [*with annotation*]

[*Source:After CDM Smith, 2018*]

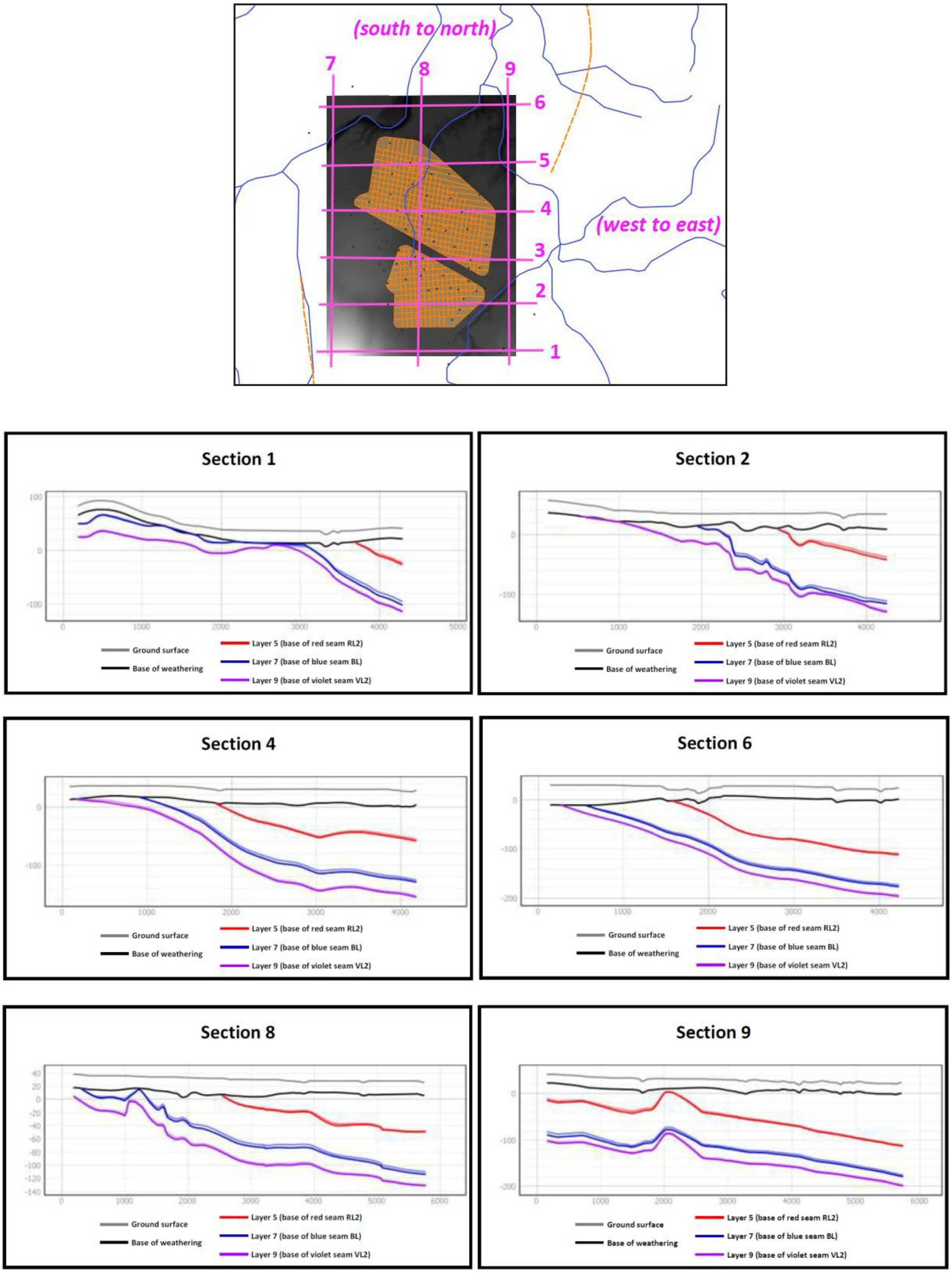


Figure 4-9

Conceptual Geological CrossSections [Based on Aggregated Seams Sourced from 2018 Geological Model (CQCPL, 2019)]

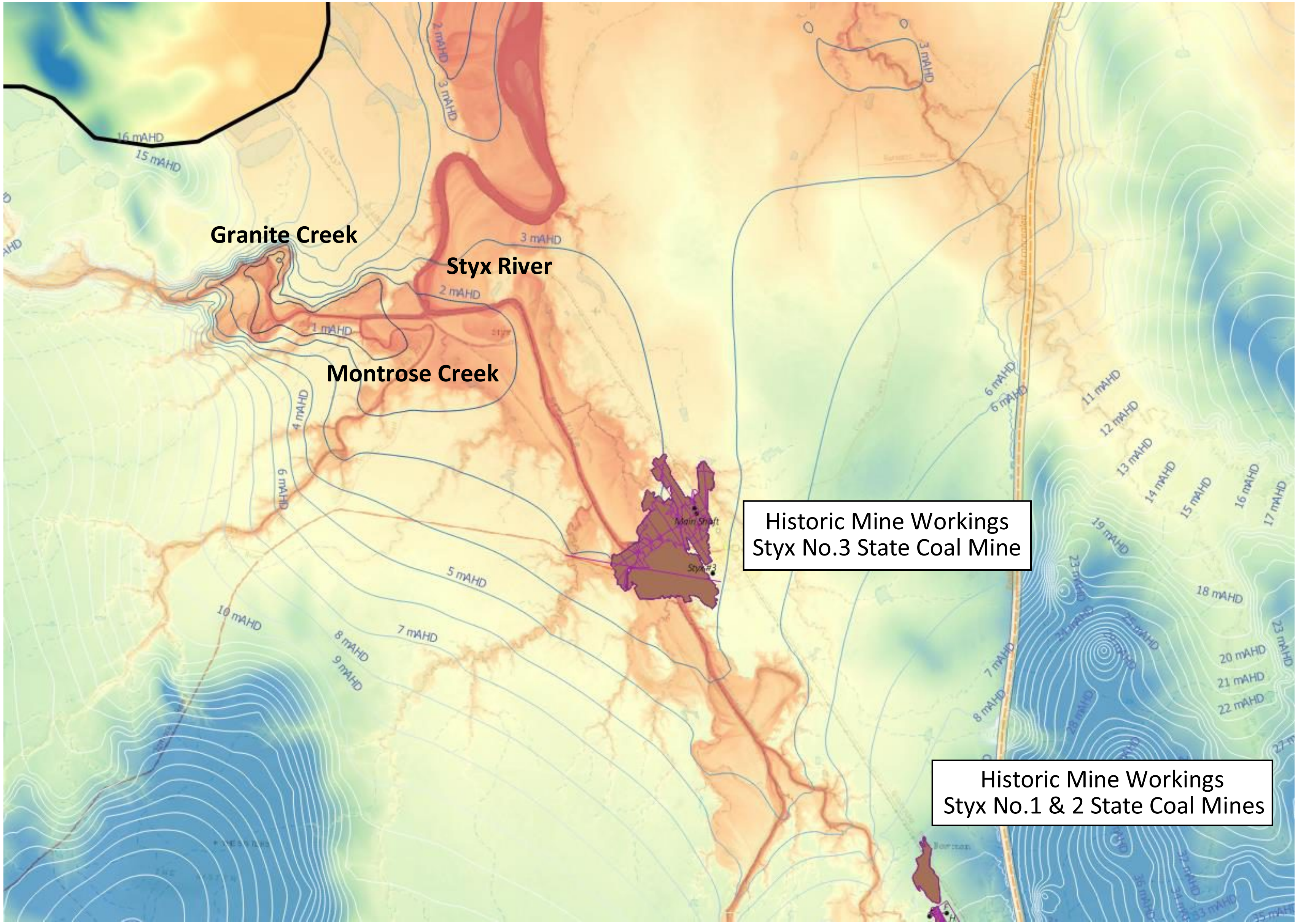


Figure 4-10

Styx River, Granite Creek and Montrose Creek Confluence

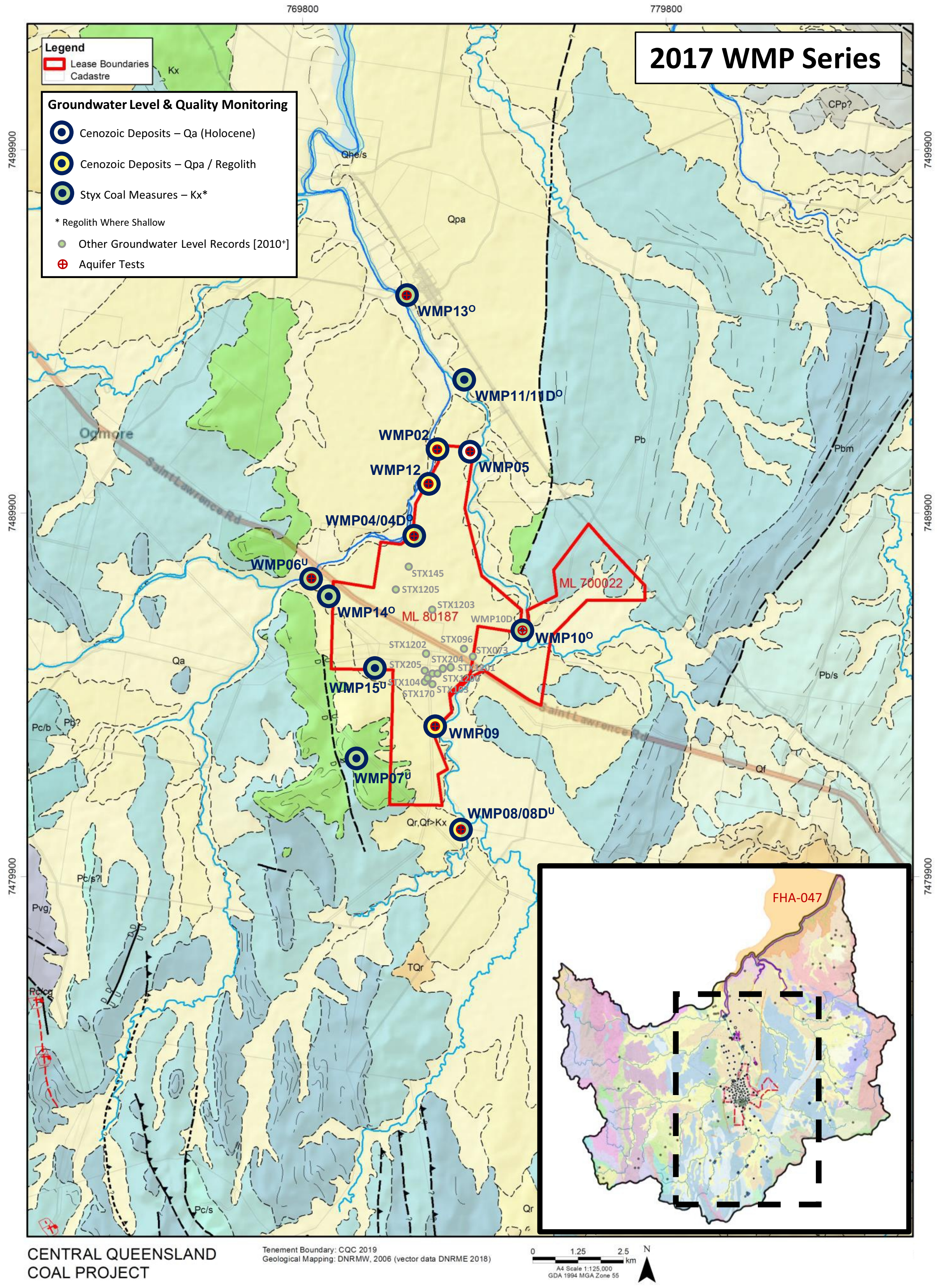
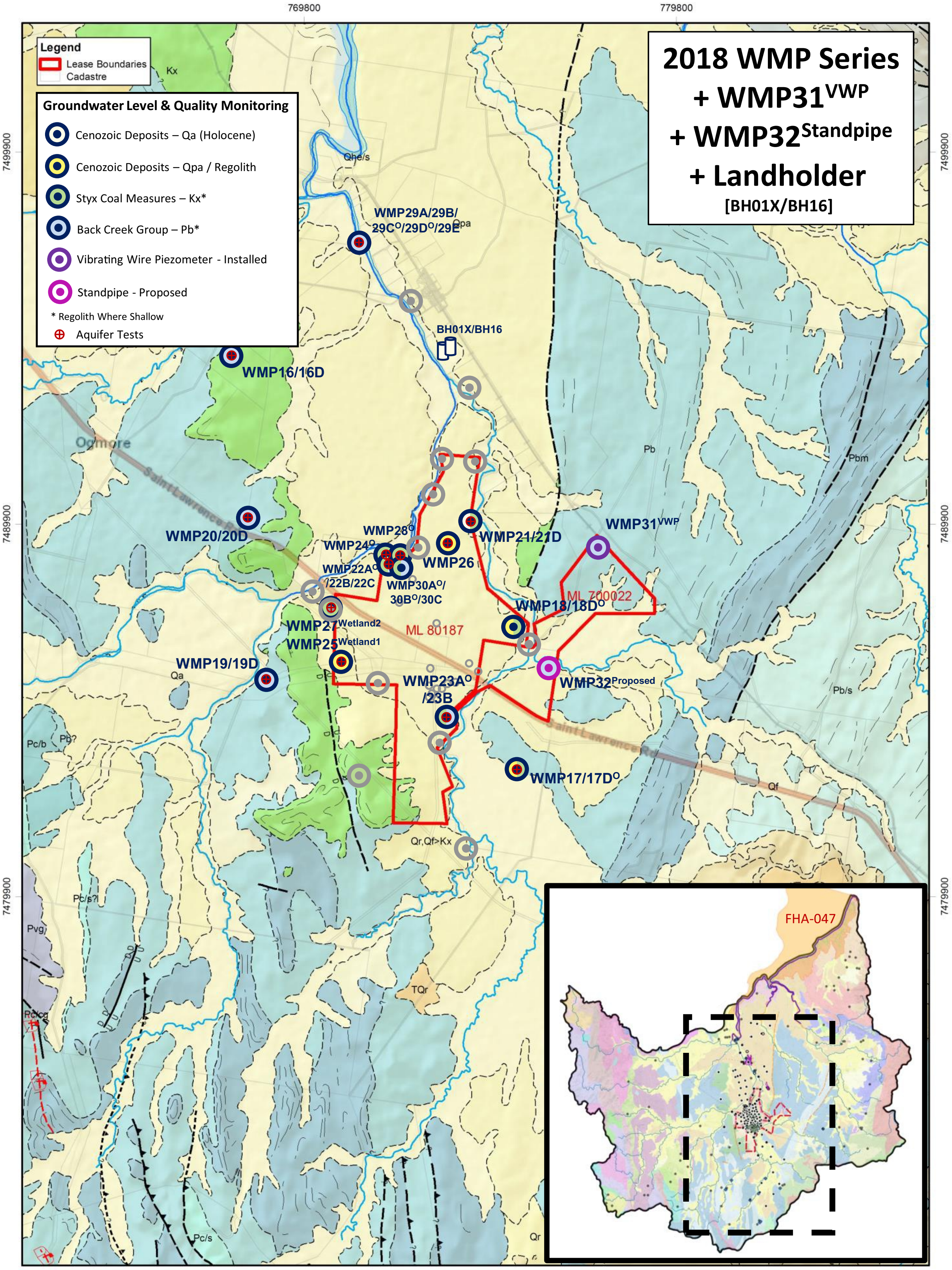


Figure 5-1[a]

Groundwater Datasets – Groundwater Monitoring and Investigations [2017 WMP Series and Other Prior [2010⁺] Exploration Drill Hole Groundwater Records]



CENTRAL QUEENSLAND
COAL PROJECT

Tenement Boundary: CQC 2019
Geological Mapping: DNRMW, 2006 (vector data DNRME 2018)

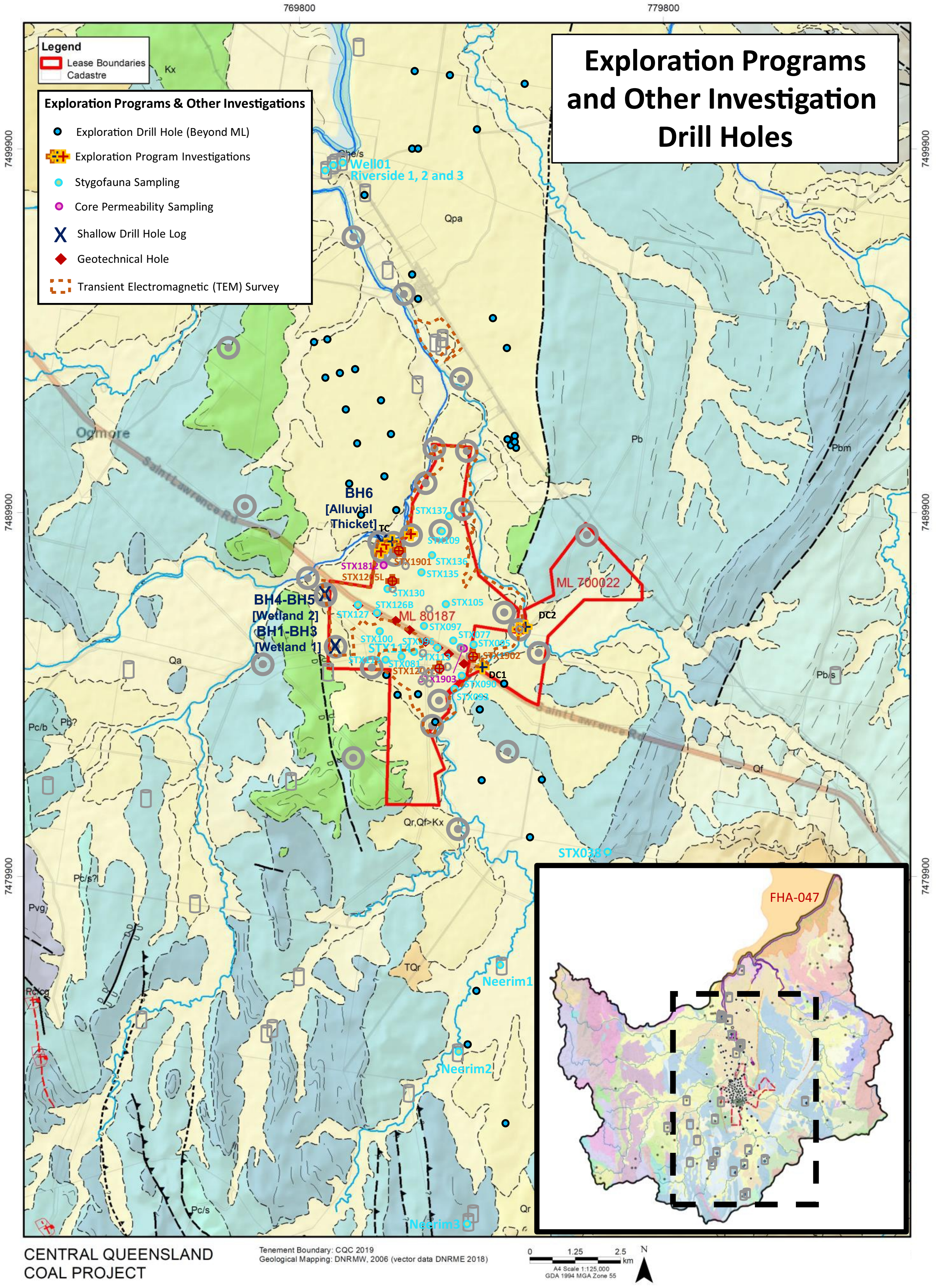
0 1.25 2.5 km
A4 Scale 1:125,000
GDA 1994 MGA Zone 55
N

HA-WAR1_V4_DRAFT_May2020

Figure 5-1[b]

Groundwater Datasets – Groundwater Monitoring and Investigations [2018 WMP Series, WMP31-32 and Landholder Monitoring Bores]

HYDRO ALGORITHMICS



CENTRAL QUEENSLAND
COAL PROJECT

Tenement Boundary: CQC 2019
Geological Mapping: DNRMW, 2006 (vector data DNRME 2018)

Figure 5-1[c]

Groundwater Datasets – Groundwater Monitoring and Investigations [Exploration Programs and Other Investigation Drill Holes]

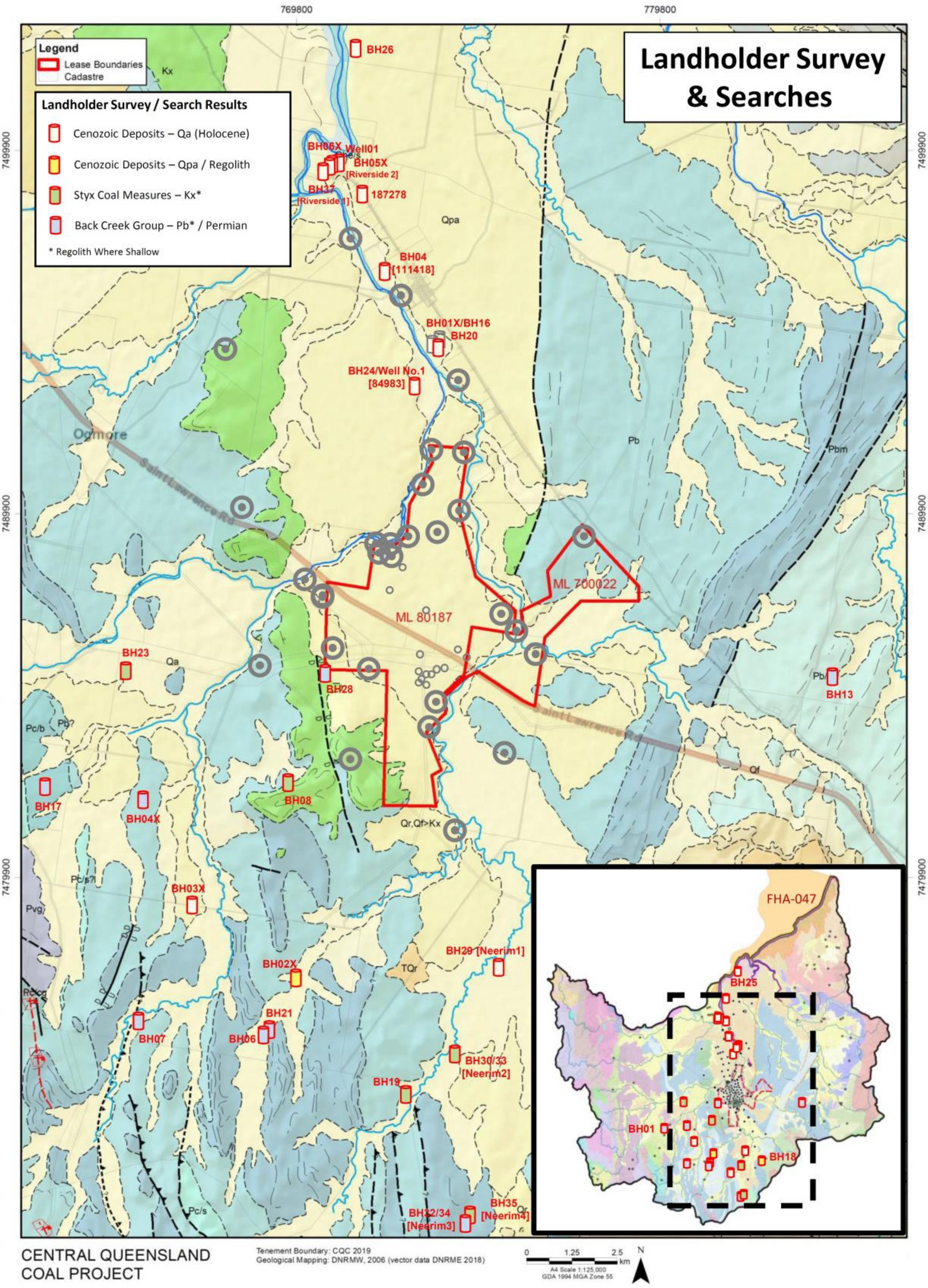


Figure 5-2

Groundwater Datasets – Landholder Survey and Government Database Search Results Reconciliation

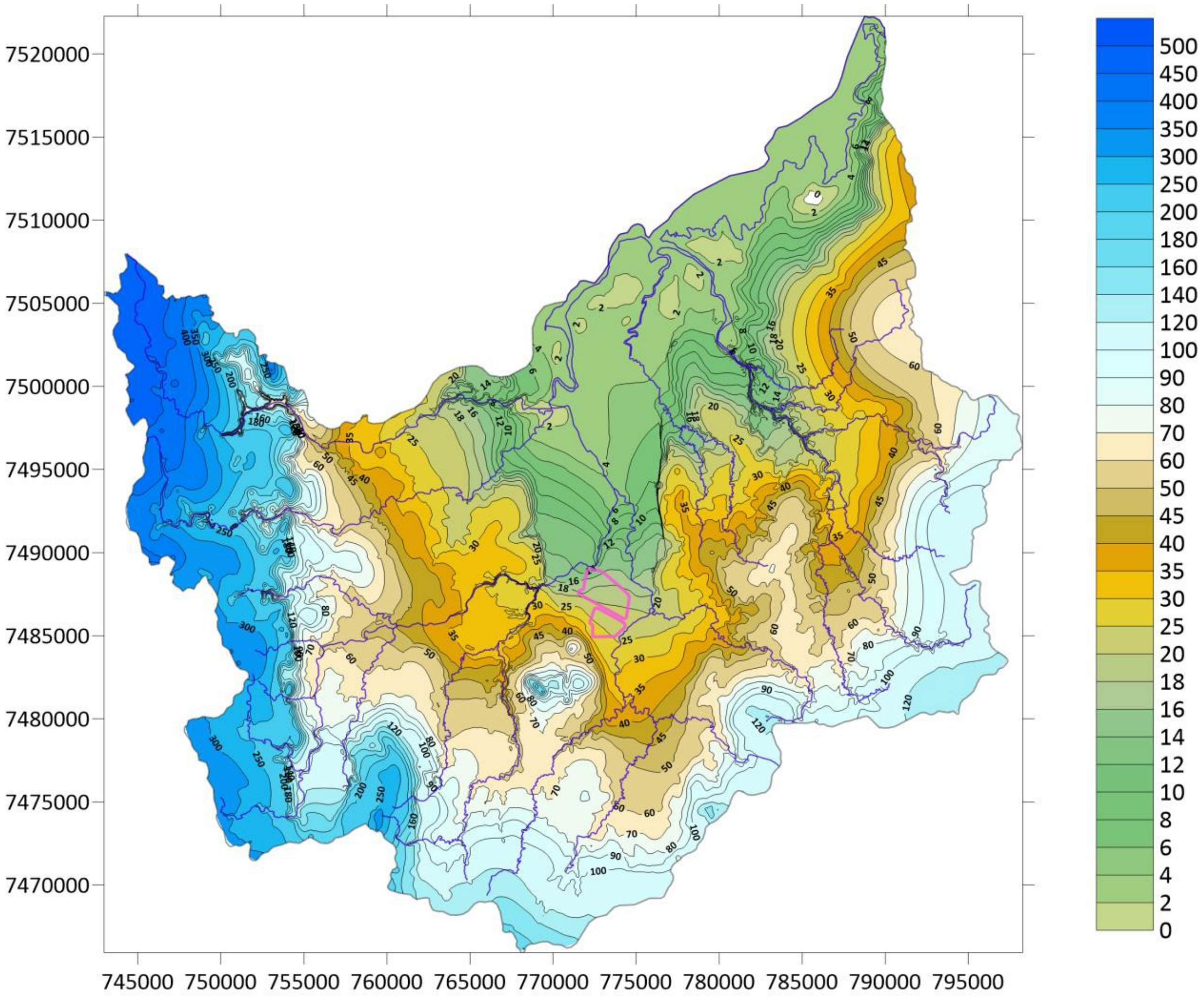


Figure 5-3

Inferred Groundwater Levels (Approximated Phreatic Surface mAHD)
in Cenozoic Deposits and Regolith – 2019 [End of Model Calibration Period]

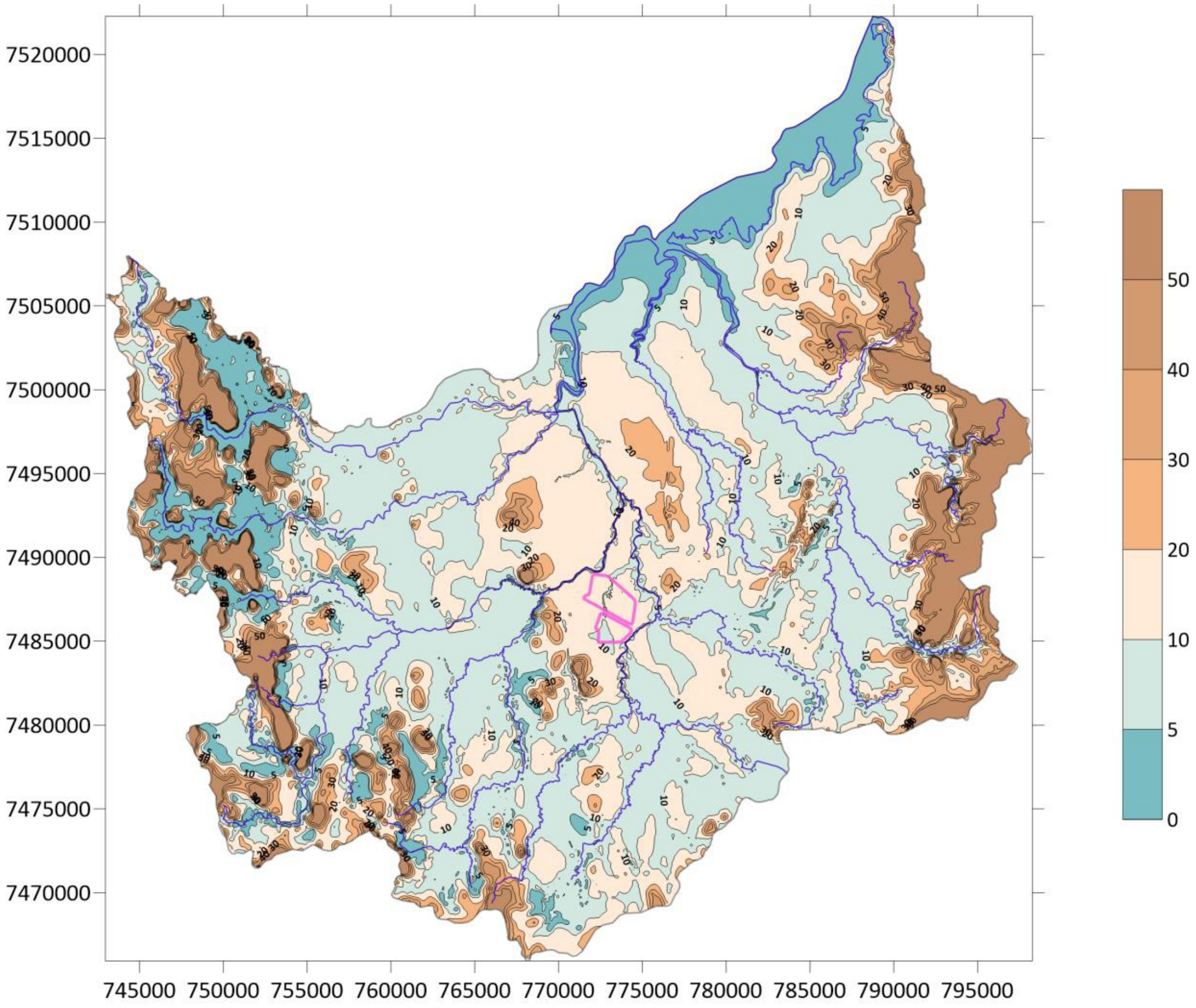


Figure 5-4

Estimated Depth to Groundwater (mbgl) in Cenozoic Deposits and Regolith - 2019
[End of Model Calibration Period]

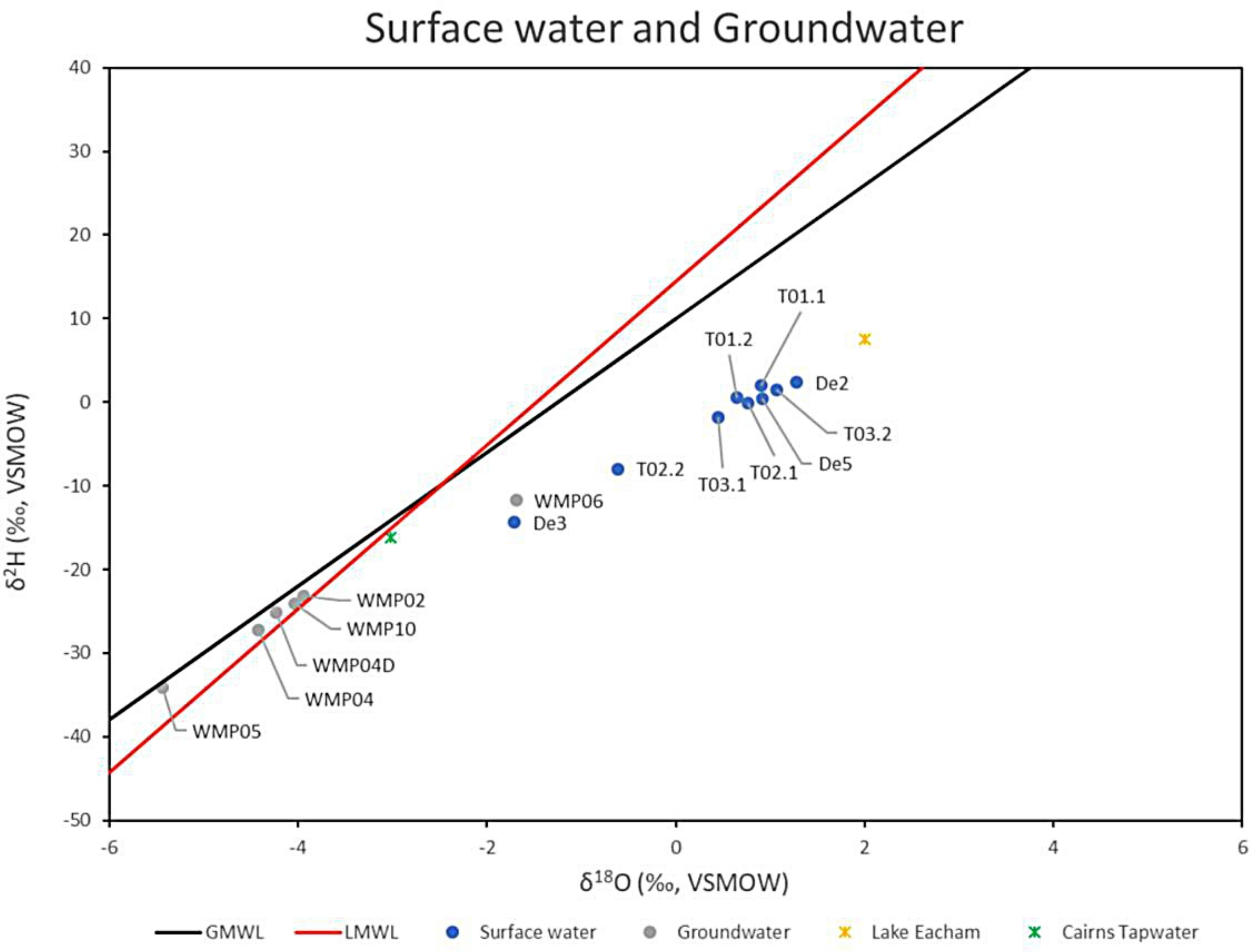
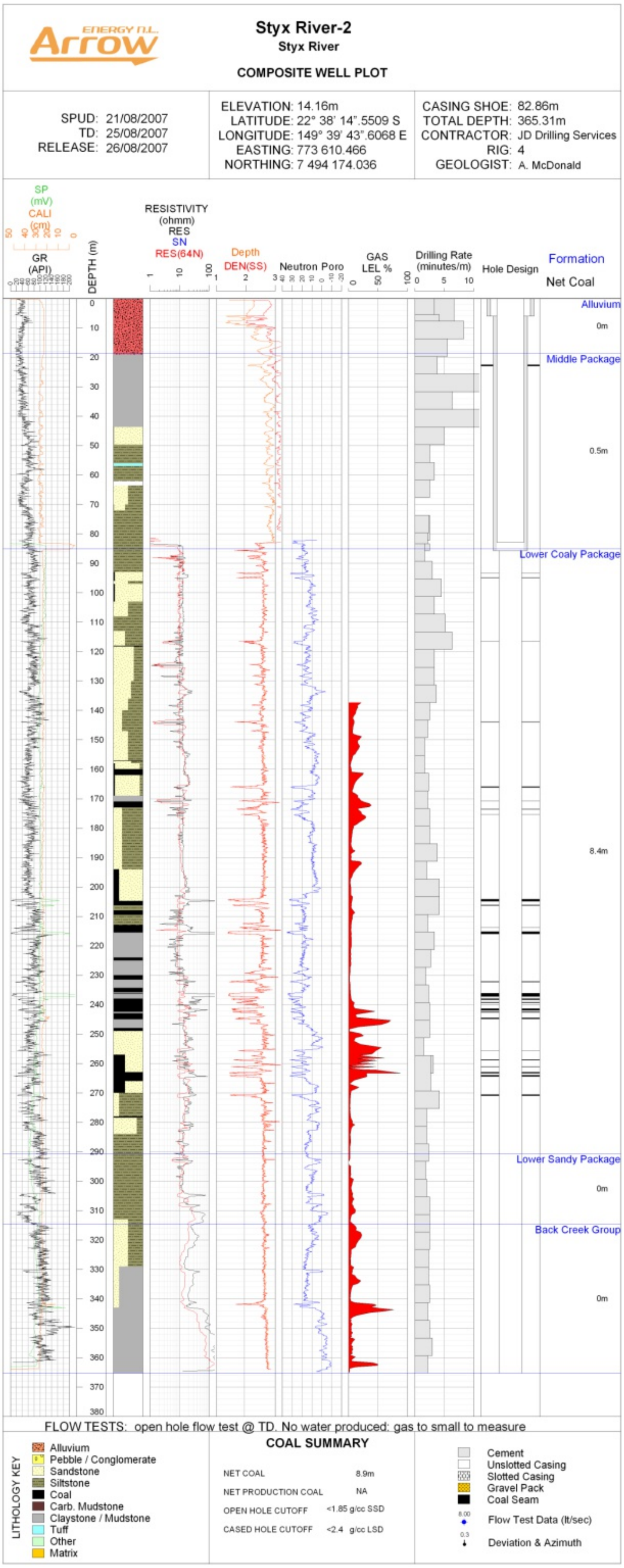


Figure 5-5

Comparison of Stable Isotopes (H-2 and O-18) in Groundwater and Surface Water

[*Source:Figure 6-1 in CDM Smith, 2018*]



Styx River-2
Styx River
COMPOSITE WELL PLOT

SPUD: 21/08/2007
TD: 25/08/2007
RELEASE: 26/08/2007

ELEVATION: 14.16m
LATITUDE: 22° 38' 14".5509 S
LONGITUDE: 149° 39' 43".6068 E
EASTING: 773 610.466
NORTHING: 7 494 174.036

CASING SHOE: 82.86m
TOTAL DEPTH: 365.31m
CONTRACTOR: JD Drilling Services
RIG: 4
GEOLOGIST: A. McDonald

FLOW TESTS: open hole flow test @ TD. No water produced: gas to small to measure

LITHOLOGY KEY
- Alluvium
- Pebble / Conglomerate
- Sandstone
- Siltstone
- Coal
- Carb. Mudstone
- Claystone / Mudstone
- Tuff
- Other
- Matrix

COAL SUMMARY

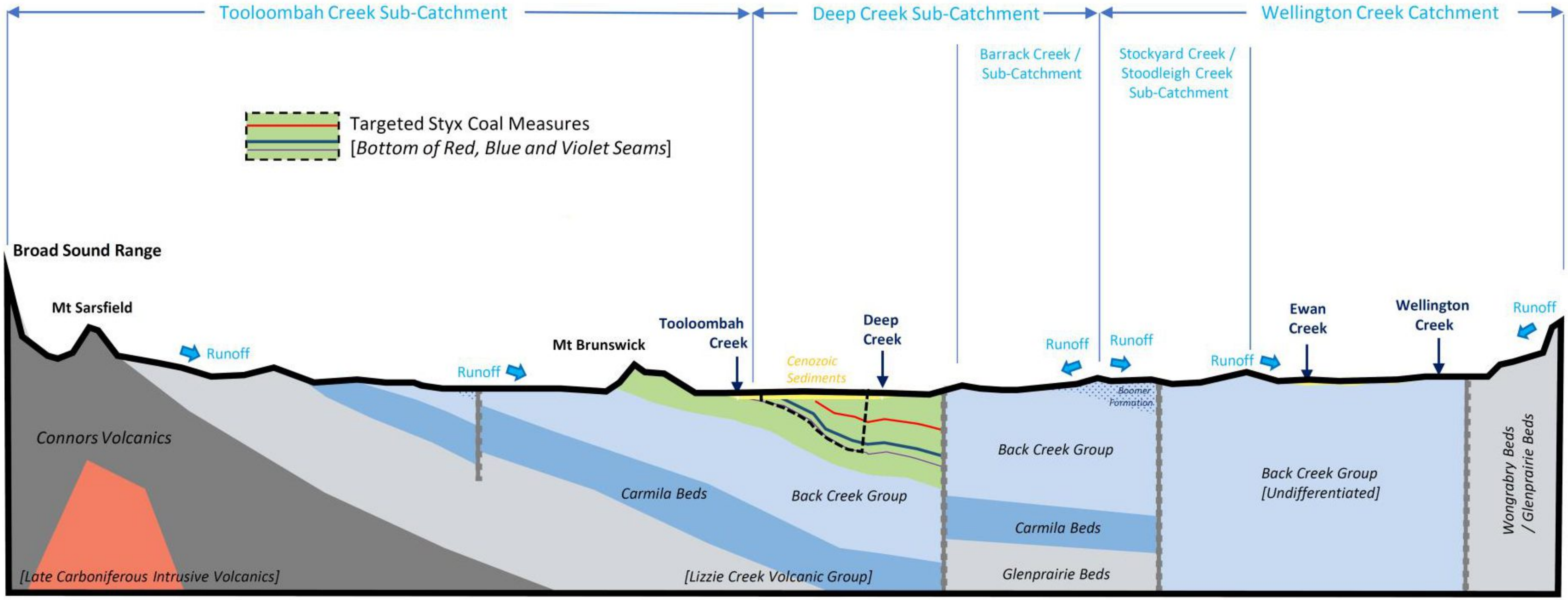
NET COAL	8.9m
NET PRODUCTION COAL	NA
OPEN HOLE CUTOFF	<1.85 g/cc SSD
CASED HOLE CUTOFF	<2.4 g/cc LSD

- Cement
- Unslotted Casing
- Slotted Casing
- Gravel Pack
- Coal Seam
- 8.00 Flow Test Data (lt/sec)
- 0.3 Deviation & Azimuth

Figure 5-6

Styx River-2 Composite Well Plot to Back Creek Group

[*Source: Arrow Energy N.L., 2007*]



Simplified Groundwater Conceptual Model – West-East Section

[Indicative Only, Not to Scale]

NB: Faults are shown as vertical for purposes of conceptualisation.

Figure 6-1

Simplified Hydrogeological Units Conceptual Model – West-East Cross Section Schematic

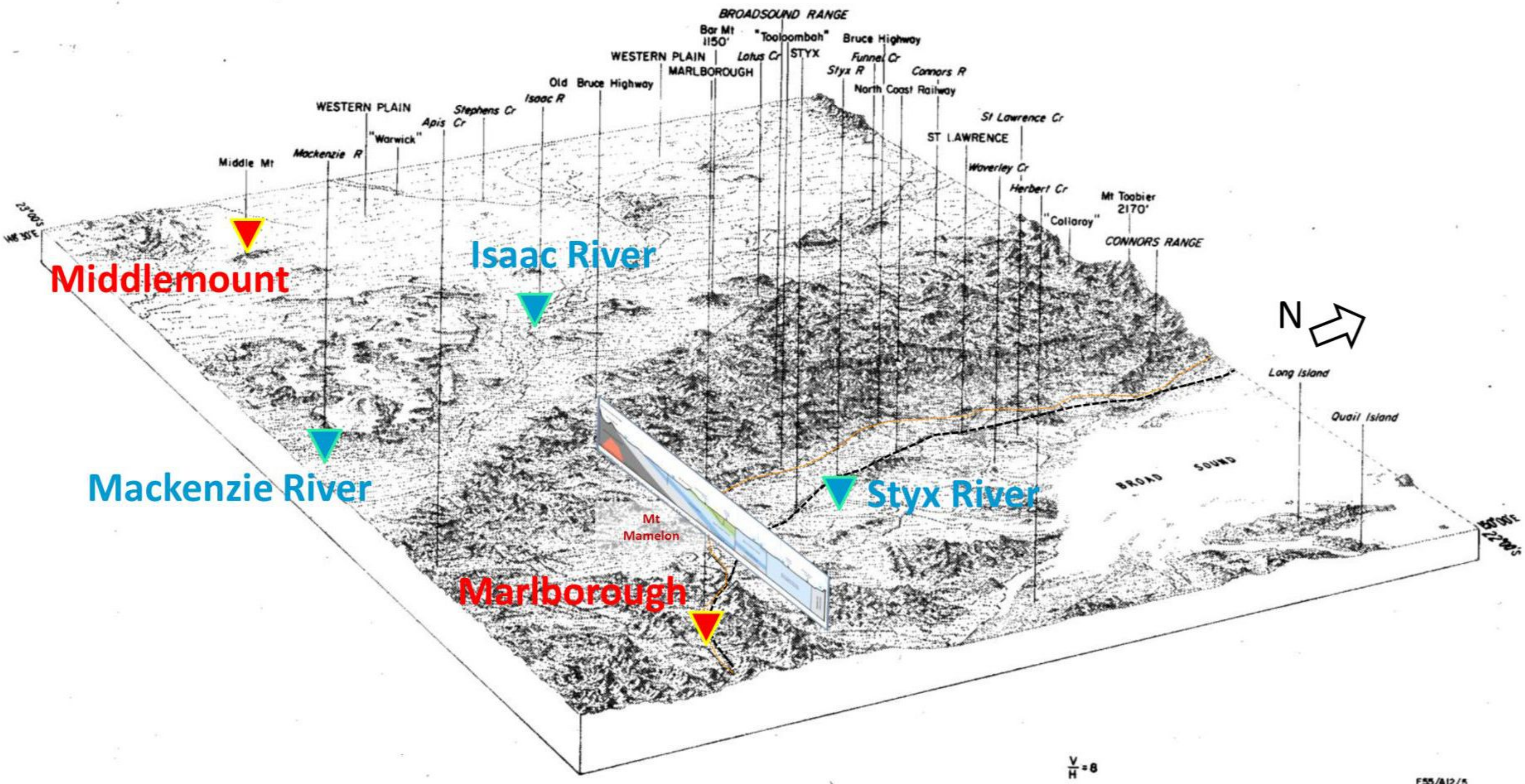


Fig. 1. Physiography of the St Lawrence Sheet area.

Figure 6-2

Regional Conceptualisation (including West-East Cross Section Schematic)

[*Source: After Figure 1 in 1:250,000 Scale Geological Series Explanatory Notes (Malone, 1964) (with annotation)*]

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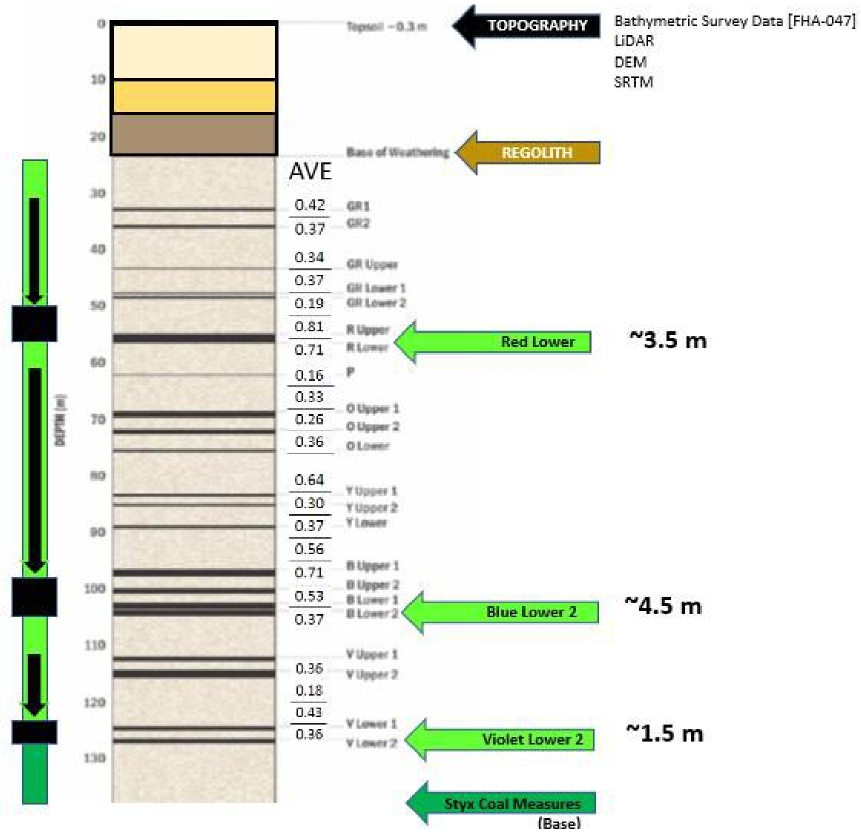
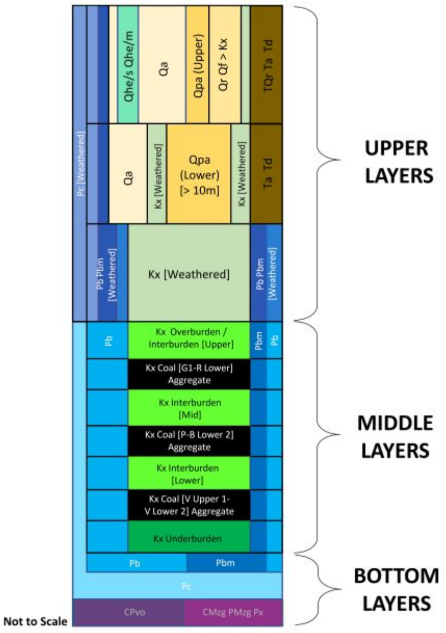




LAYER 1 – Inactive for Potential Future Inclusion of Elevated Landforms

LAYER 2 – Quaternary / Tertiary / Weathered (Regolith)

LAYER 3 – Quaternary / Tertiary / Weathered (Regolith)

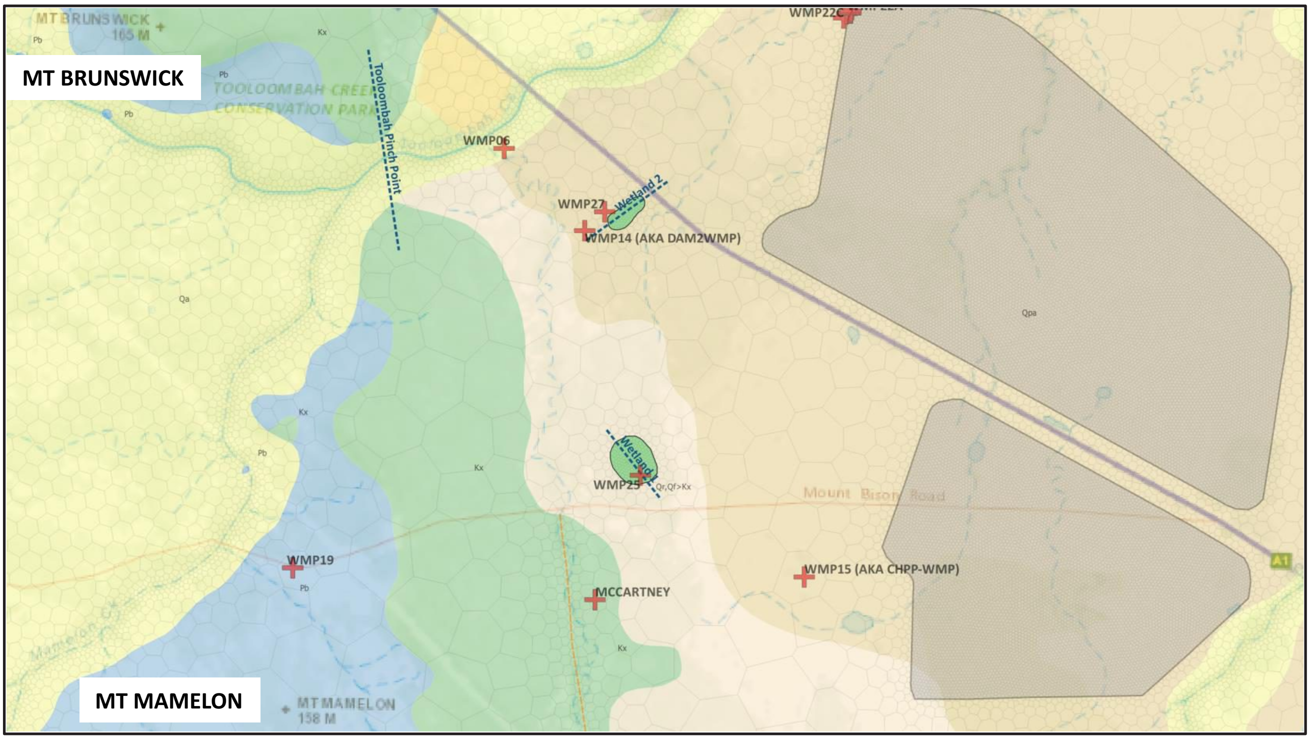
LAYER 4 – Weathered (Regolith)

LAYER 5 – Styx Overburden / Interburden (Upper)
LAYER 6 – COAL (RED SEAM) [~3.5 m] [*Top Working Seam (Ogmore)*]
LAYER 7 – Styx Interburden
LAYER 8 – COAL (BLUE SEAM) [~4.5 m] [*Bottom Working Seam (Ogmore)*]
LAYER 9 – Styx Interburden
LAYER 10 – COAL (VIOLET SEAM) [~1.5 m] [*Lower Seam (Ogmore)*]
LAYER 11 – Styx Underburden
LAYER 12 – Back Creek Group (including Boomer Formation)
LAYER 13 – Lizzie Creek Volcanic Group (including Carmila/Glenprairie/Wangrabry Beds
LAYER 14 – Intrusive Rocks / Connors Volcanic Group
BASEMENT – to 500 m Depth

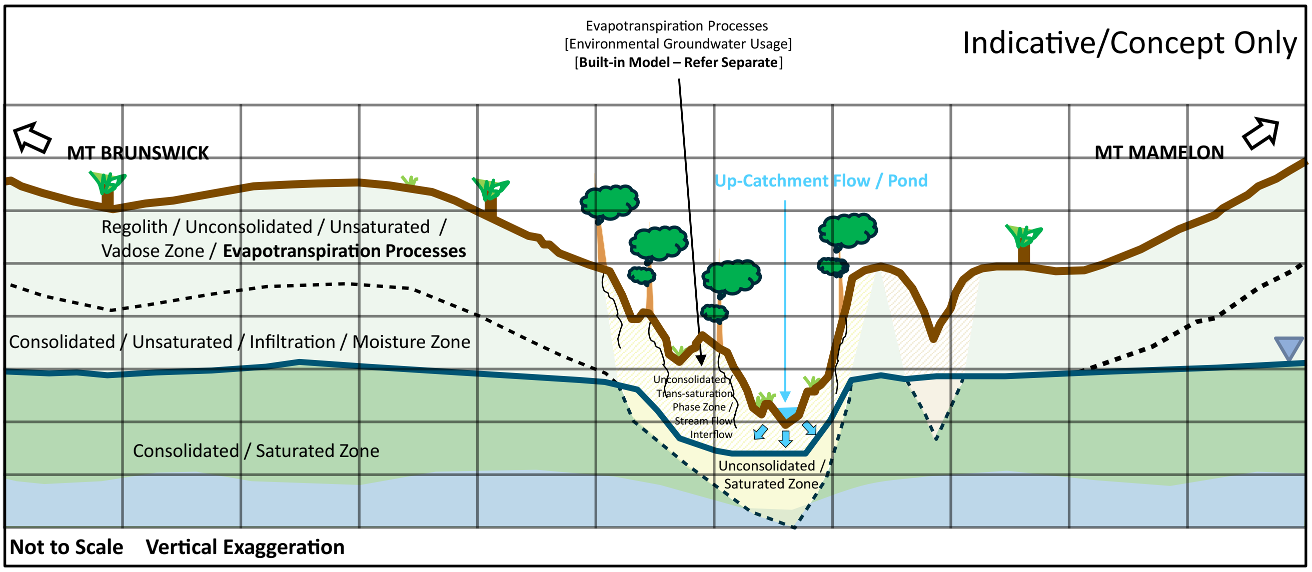
Figure 6-3

Conceptualisation for Groundwater Model Layers

(includes stratigraphic section as presented in Figure 5-6 of CDM Smith 2018)

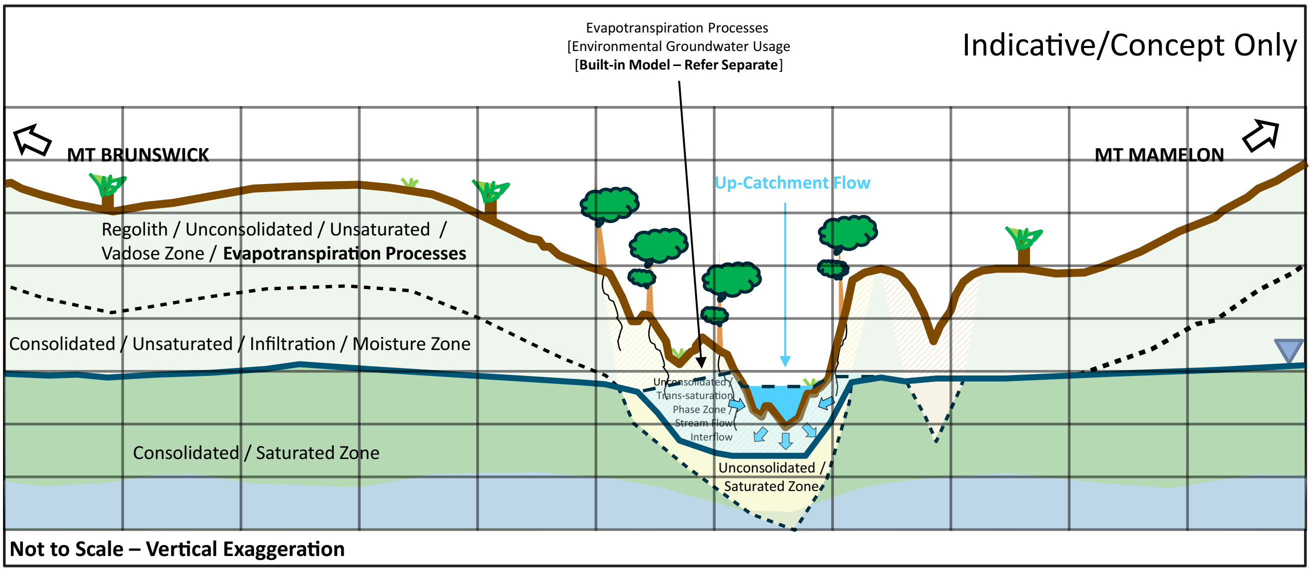


Preliminary Eco-Hydrogeological Conceptualisations – Plan View

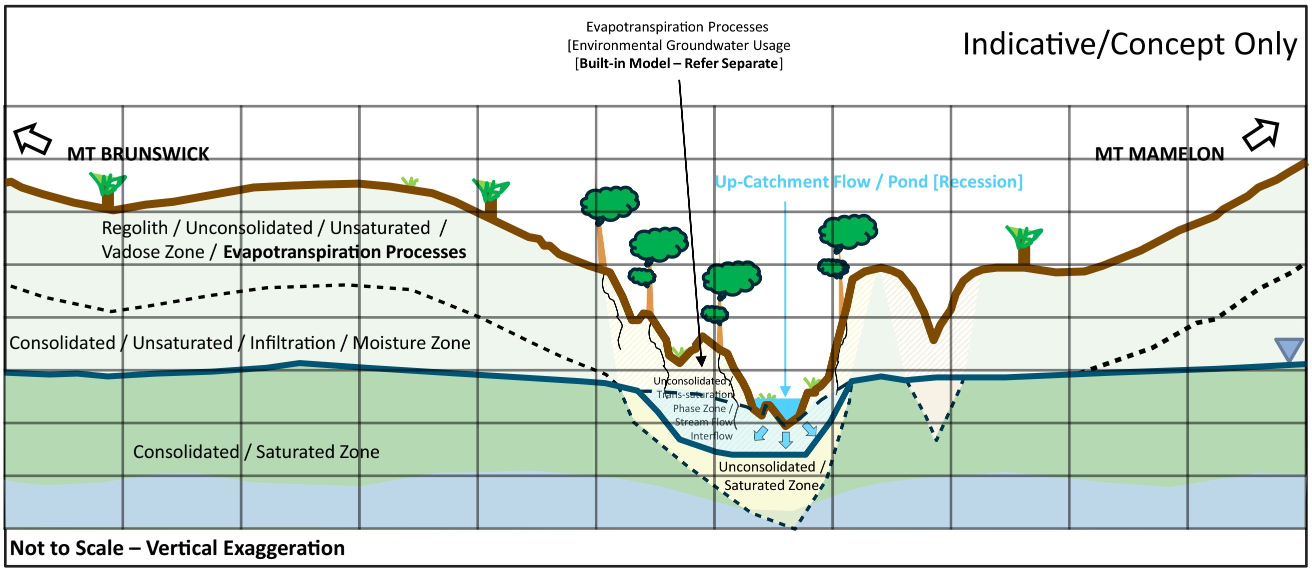


Tooloombah Creek Pinch Point Conceptualisation – Cross-Sections
{i} Long-term/Equilibrated Conditions

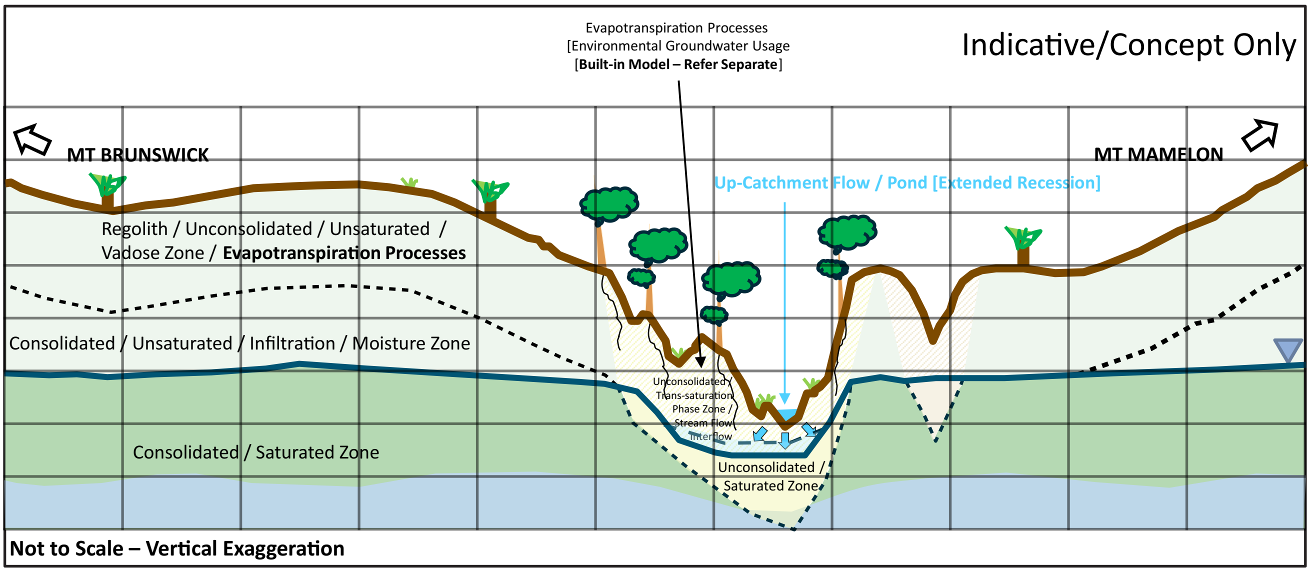
Figure 6-4(a)
Conceptualisations



{ii} During Rainfall / Flood Recharge Event



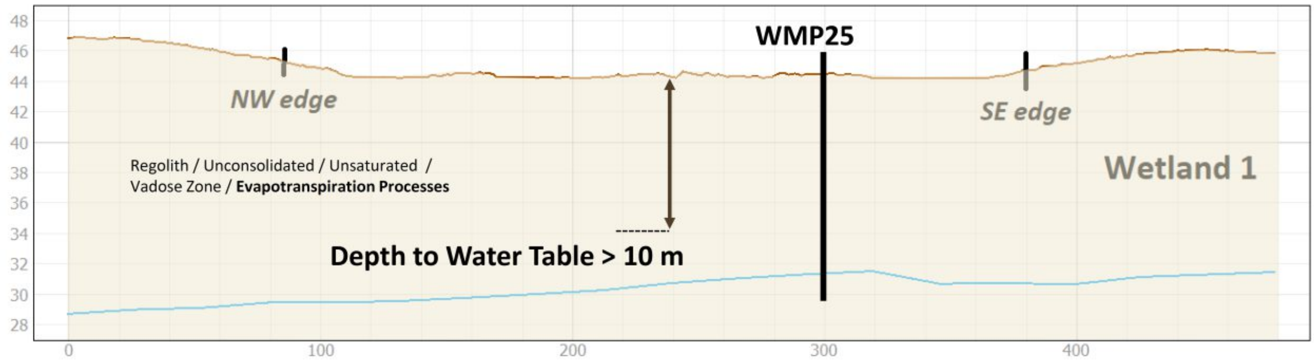
{iii} Interflow after Rainfall / Flood Recharge Event



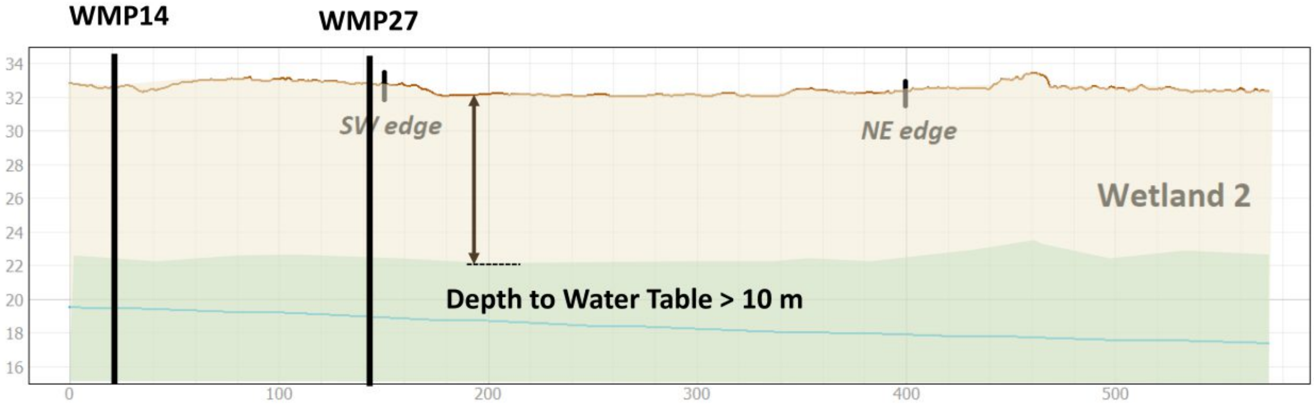
{iv} Extended Period after Rainfall / Flood Recharge Event

Figure 6-4(b)

Tooloombah Creek Pinch Point Conceptualisation – Cross-Sections



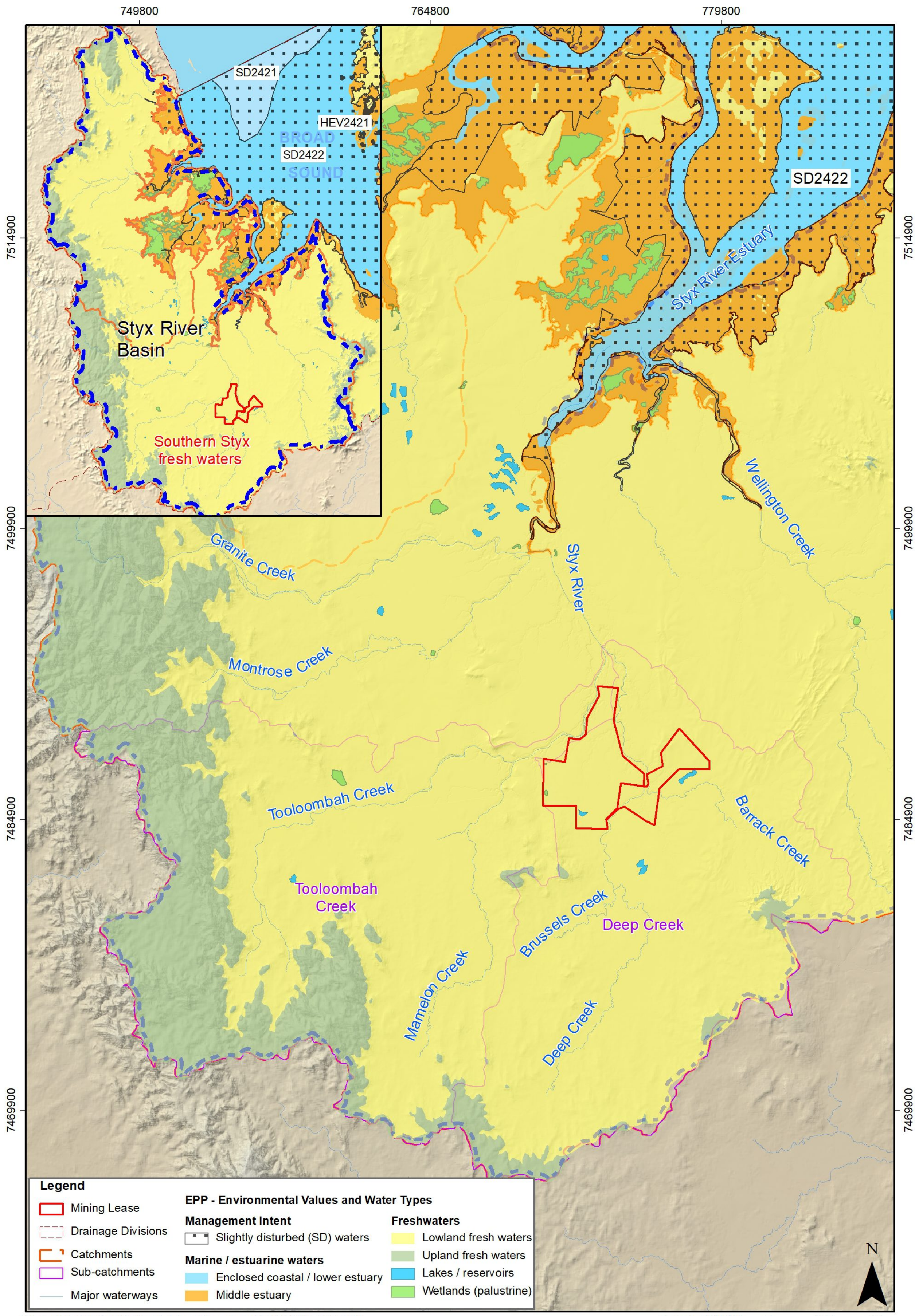
(a) Wetland 1 Conceptualisation – Cross-Section



(b) Wetland 2 Conceptualisation – Cross-Section

Figure 6-5

Wetland Conceptualisations



Water EPP: DEHP 2017 | Styx Catchment Boundary: DNRME 2019, CQC 2020
ML Boundary: CQC 2020 | Basemap: DNRME 2006

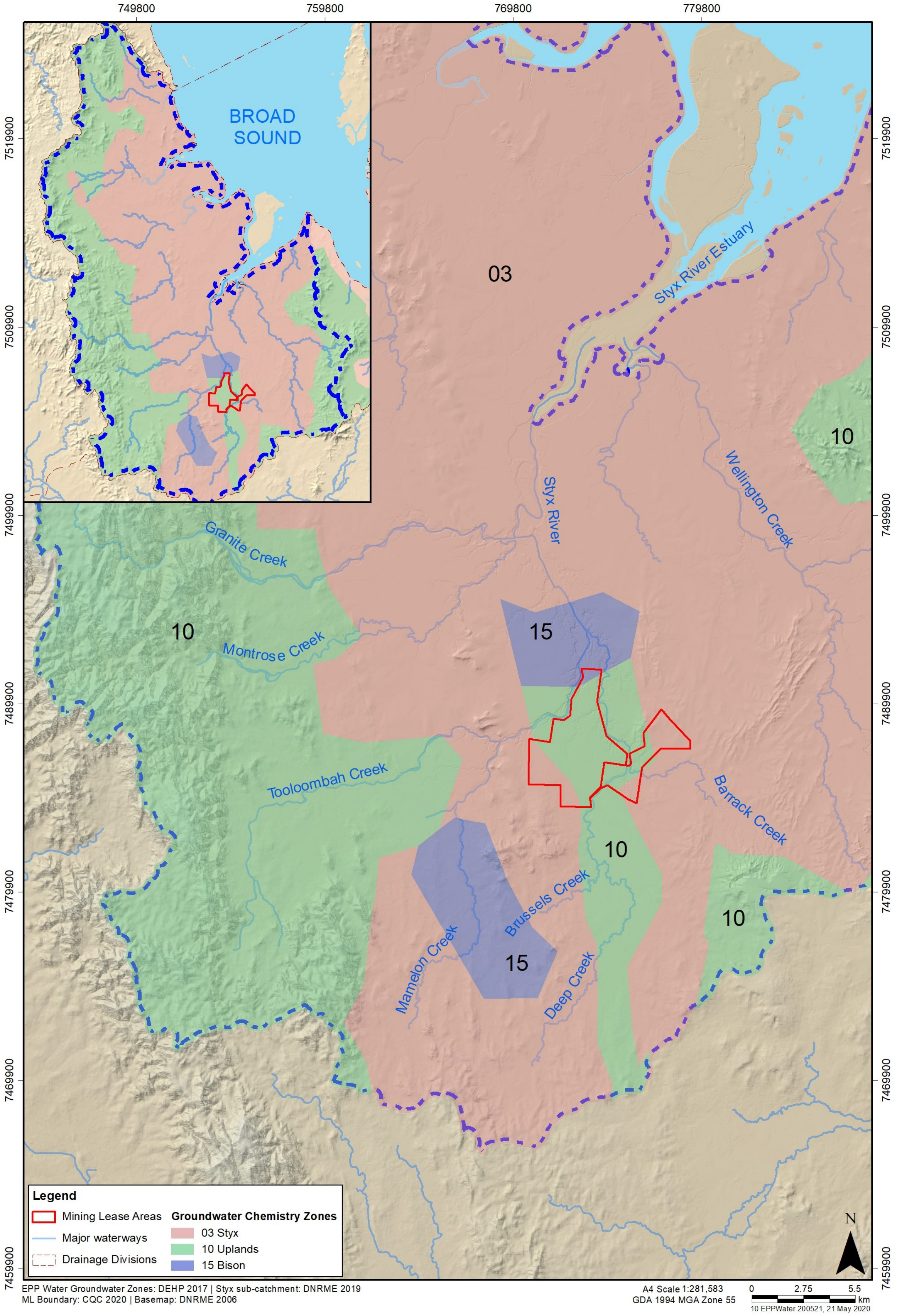
A4 Scale 1:280,000
GDA 1994 MGA Zone 55

09 EPPWater 200521, 21 May 2020

Figure 6-6

Styx River, Shoalwater and Water Park Creek Basins (WQ1271) and Capricorn Curtis Coastal Waters (WQ1272)

[*Source: CQCPL, 2020*]



EPP Water Groundwater Zones: DEHP 2017 | Styx sub-catchment: DNRME 2019
ML Boundary: CQC 2020 | Basemap: DNRME 2006

A4 Scale 1:281,583
GDA 1994 MGA Zone 55

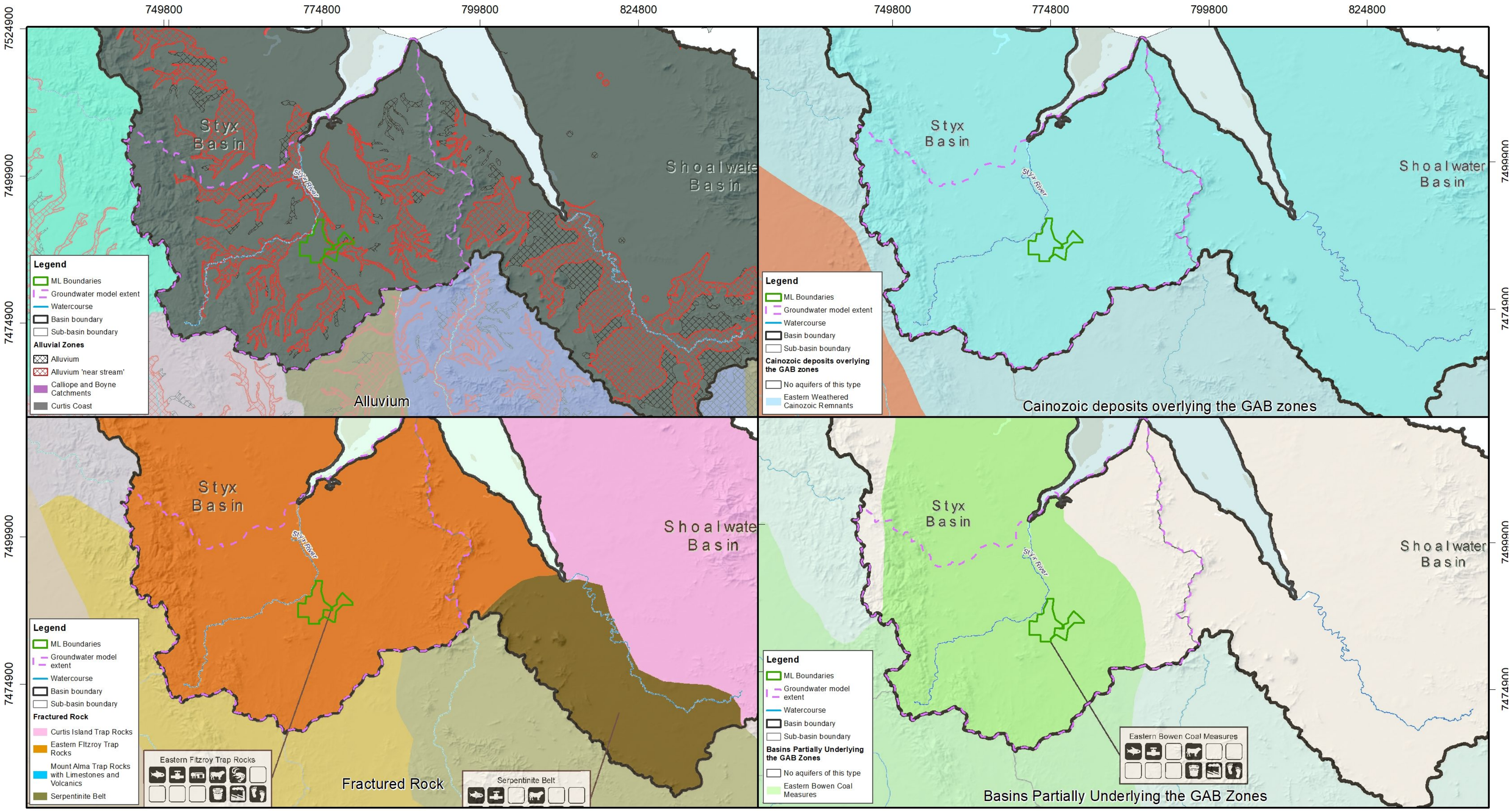
10 EPPWater 200521, 21 May 2020

HA-WAR1_V4_DRAFT_May2020

Figure 6-7

Capricorn Curtis Coast Groundwater Map Zones (WQ1273)

[*Source: CQCPL, 2020*]



Sources: Draft Water EPP Groundwater Zones: McNeil et al 2018 (Qld DES)
ML Boundary: CQC 2020 | Model boundary: HA 2020

A4 Scale 1:900,000
GCS GDA 1994
0 5 10 km
10 GW 2018 Draft Water EPP 200521, 21 May 2020

Figure 6-8

Draft Capricorn Curtis Coast Groundwater Maps – Alluvium (GWQ1271); Fractured Rock (GWQ1272); Cainozoic Deposits Overlying the GAB Zones (GWQ1273); and Basins Partially Underlying the GAB Zones (GWQ1279)

[Source: CQCPL, 2020]

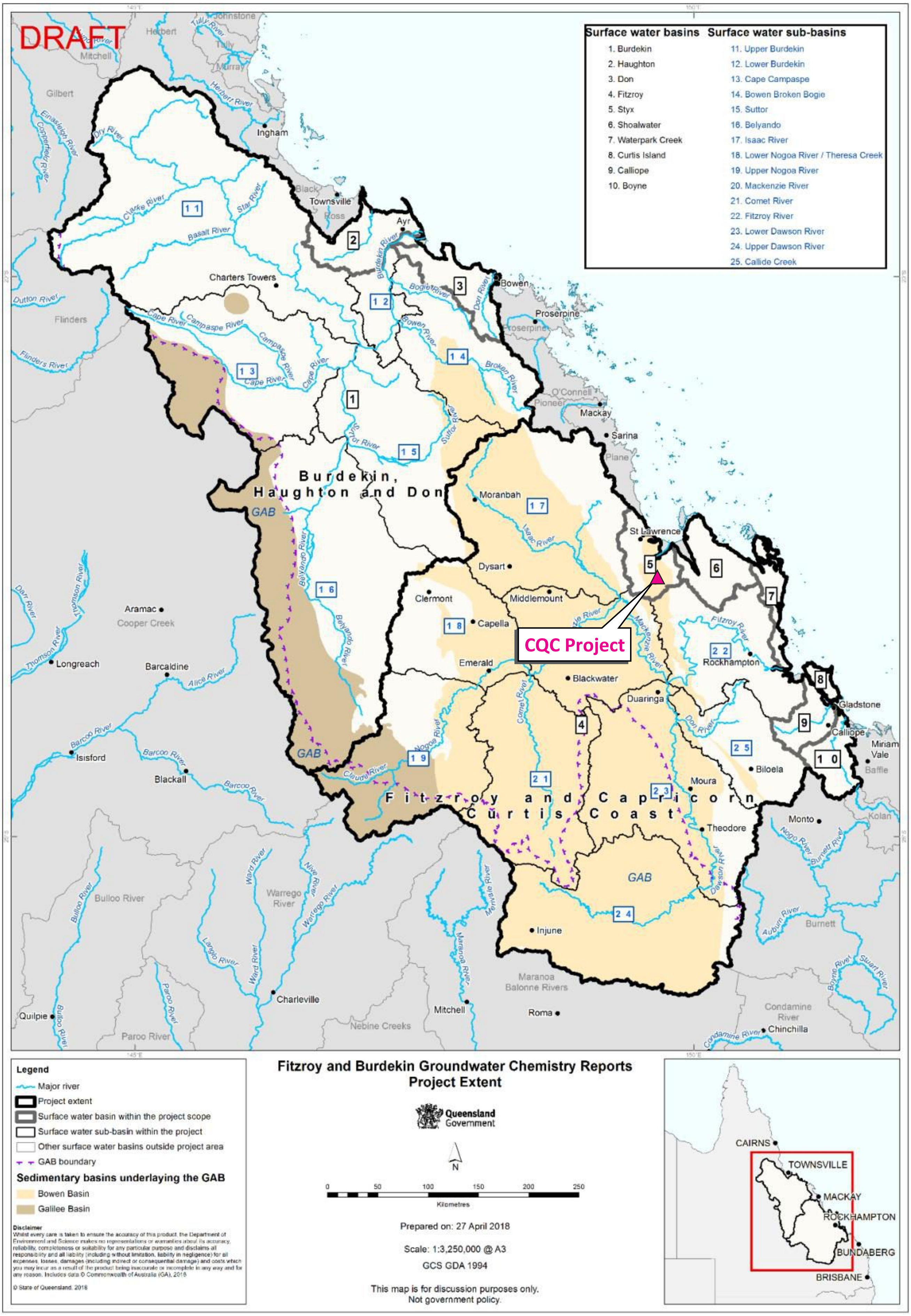


Figure 6-9

Fitzroy and Burdekin Groundwater Chemistry Reports Project Extent [*with annotation*]

[*Source: Qld Government Department of Environment and Science, 2018*]

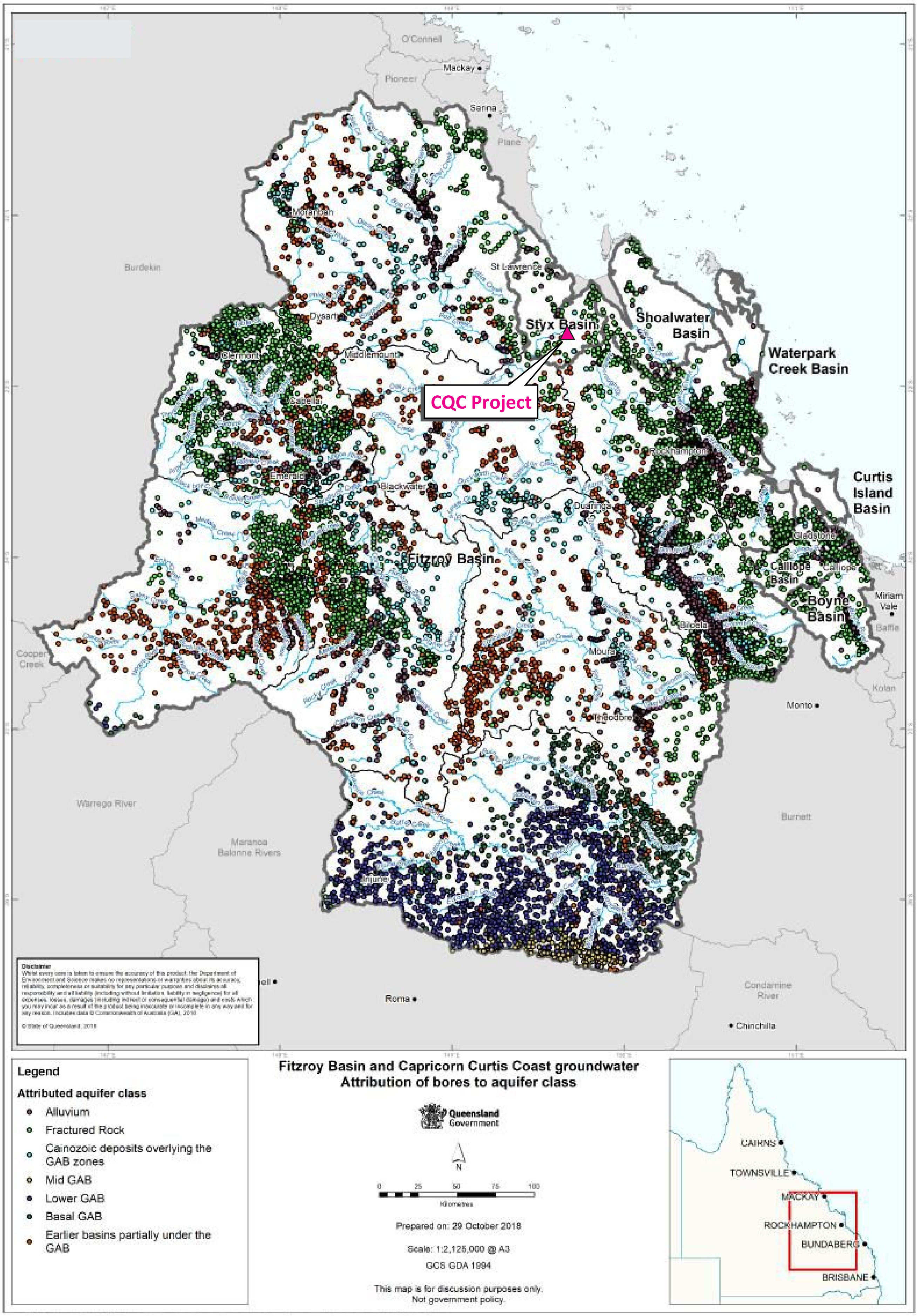


Figure 6-10

Fitzroy Basin and Capricorn Curtis Coast Groundwater - Attribution of Bores to Aquifer Class

[*Source: Figure 23 in Qld Government Department of Environment and Science, 2018* (with annotation)]

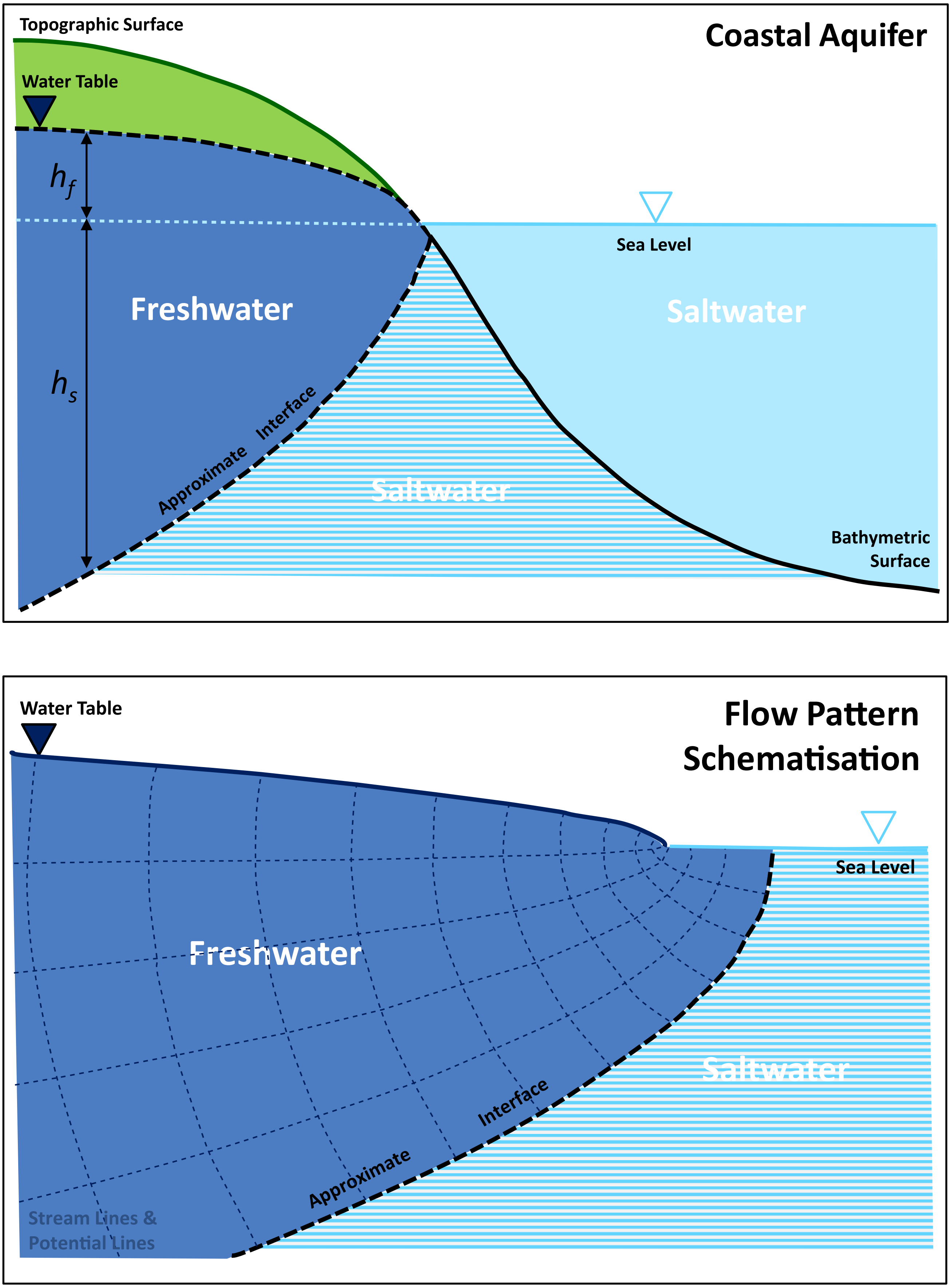


Figure 6-11

Ghyben-Herzberg Relationship and Flow Pattern Schematisation

[*Source: After Figures 1 & 2 in Verruijt, A., 1968*]

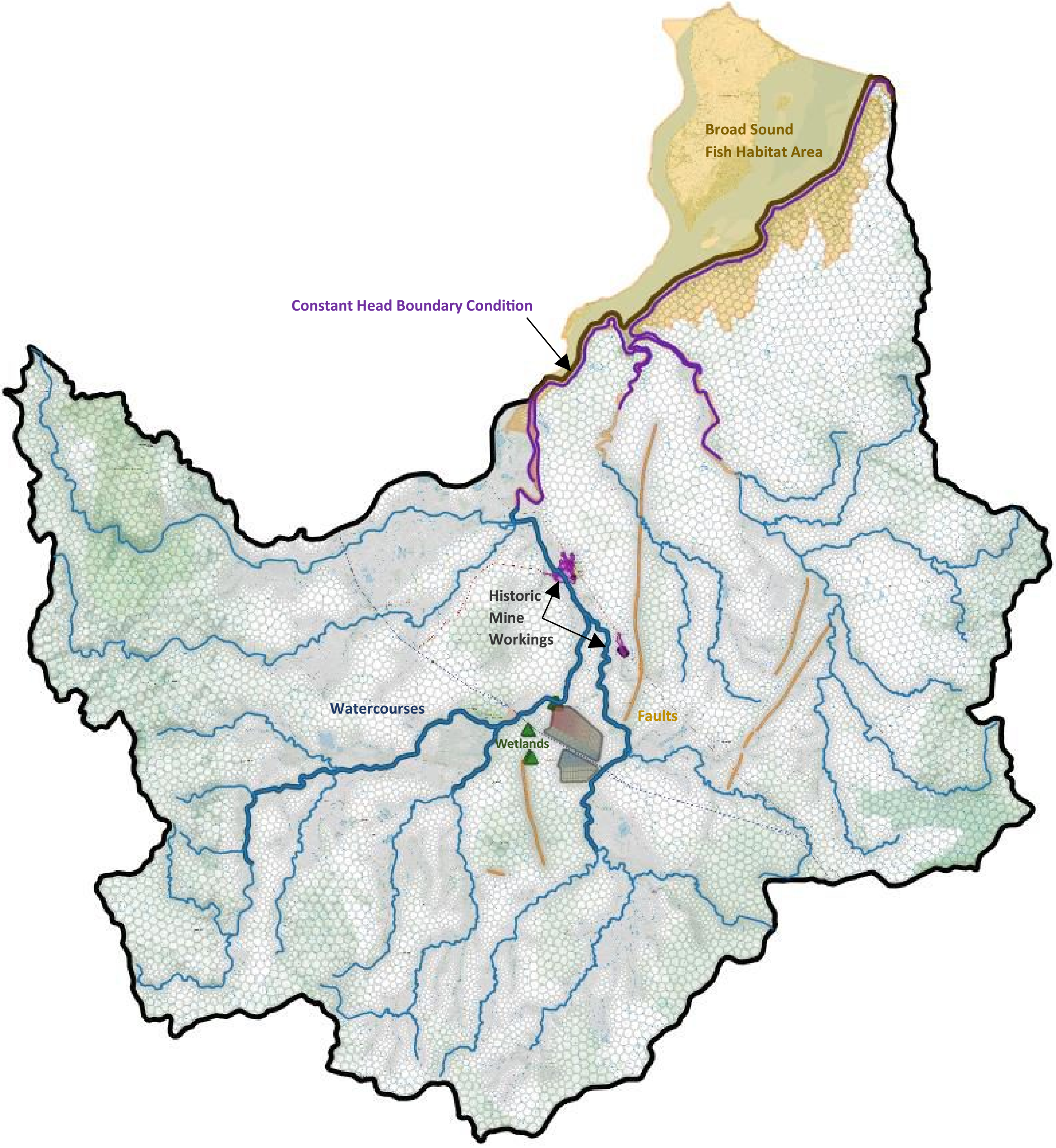


Figure 7-1

Numerical Groundwater Flow Model Domain and Mesh Refinement

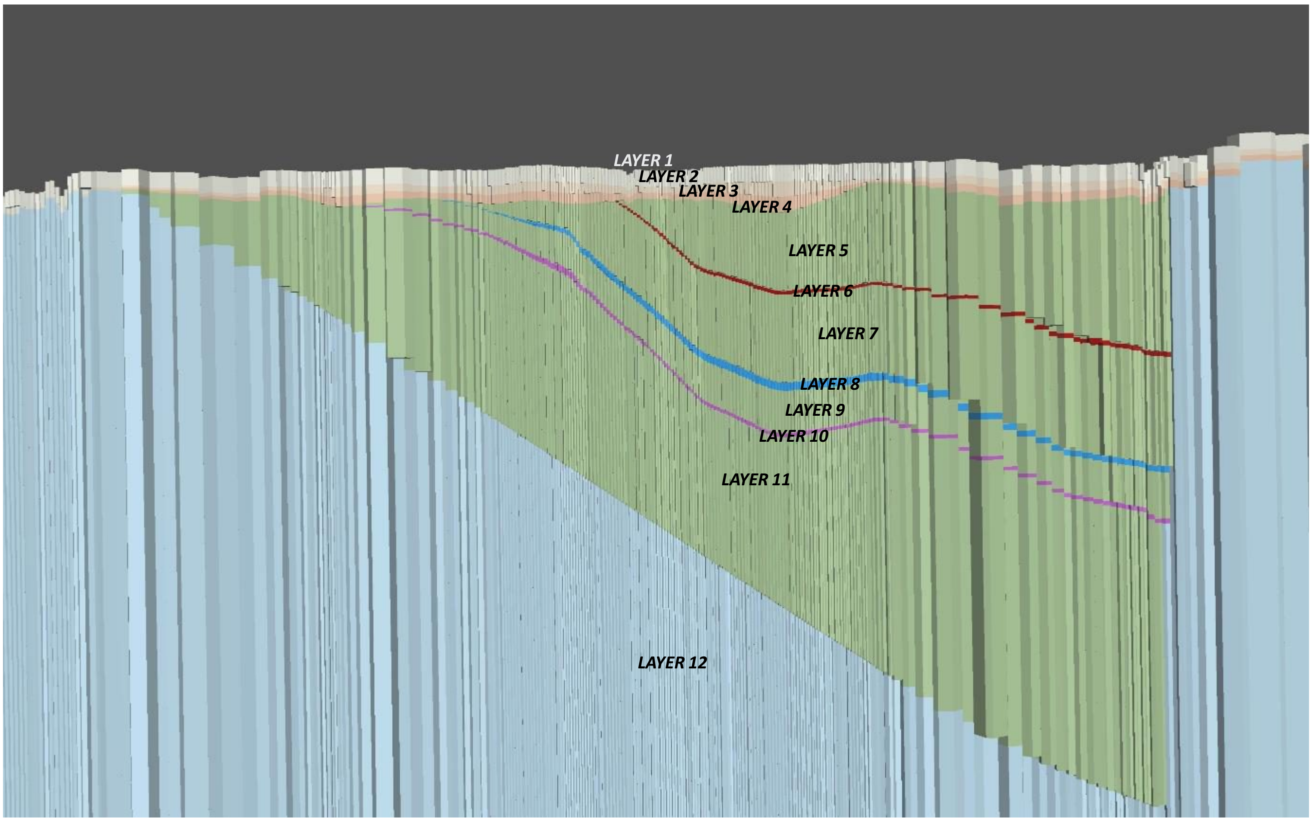


Figure 7-2

Numerical Groundwater Flow Model [Top and Middle Layers - Cenozoic Deposits, Regolith and Styx Coal Measures]

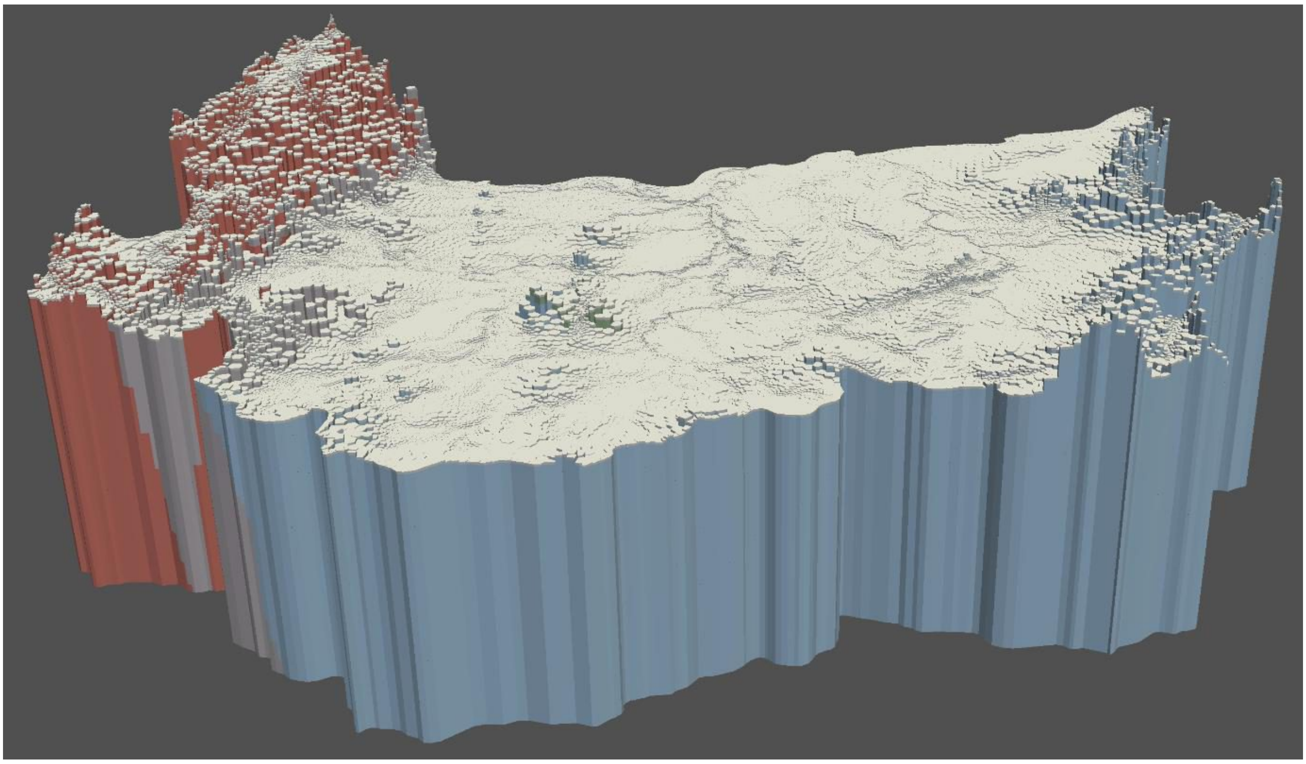


Figure 7-3

Numerical Groundwater Flow Model [Bottom Layers and Basement - Permian and Volcanics]

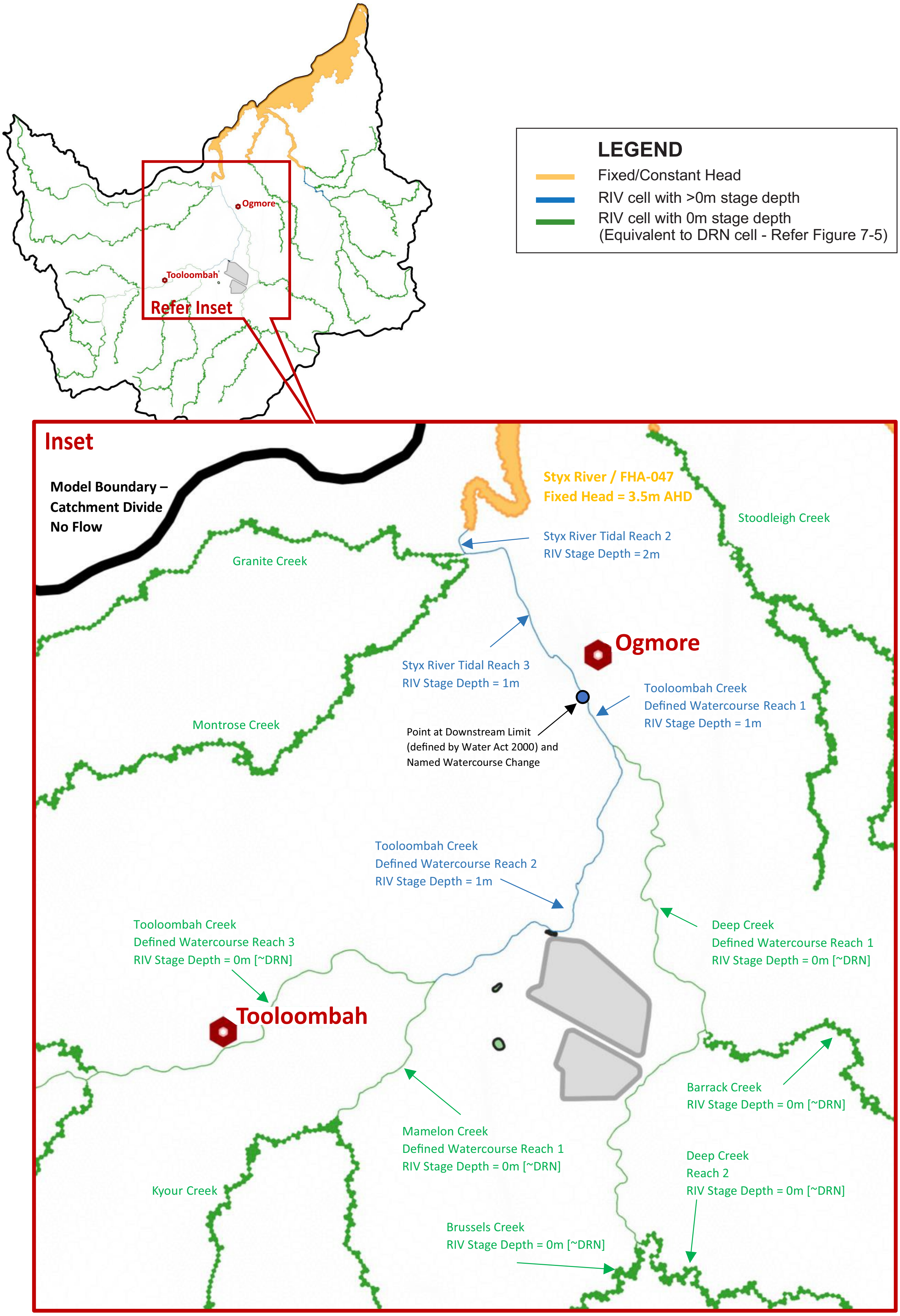
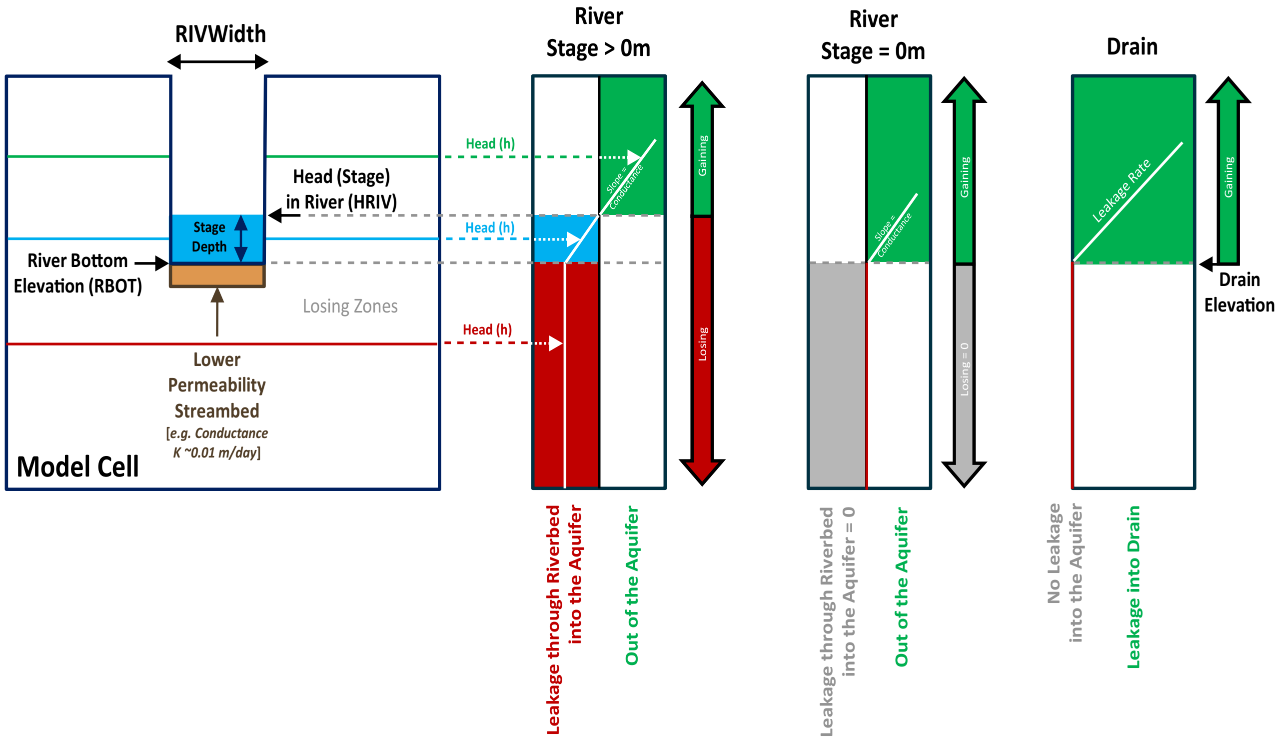


Figure 7-4

Numerical Groundwater Flow Model – Boundary Conditions Across Model Domain



Underlying Modelling Assumptions – River Cell Budgets

Assumes direct hydraulic connection between the river and the underlying aquifer.

No limit on the volume of water that can leak from the river to the underlying aquifer.

The concept of 'losing zones' is the river can be physically separated from the underlying water table by unsaturated zones.

This is often confused when quantifying baseflow loss (and/or enhanced leakage) from 'gaining' and 'losing' stream reaches.

Therefore, when drawdown occurs within the zones beneath the unsaturated zone it does not in reality increase the rate of flux (leakage) from the river, as the model would report.

Figure 7-5

Numerical Groundwater Flow Model – Drain Cell versus River Cell Function

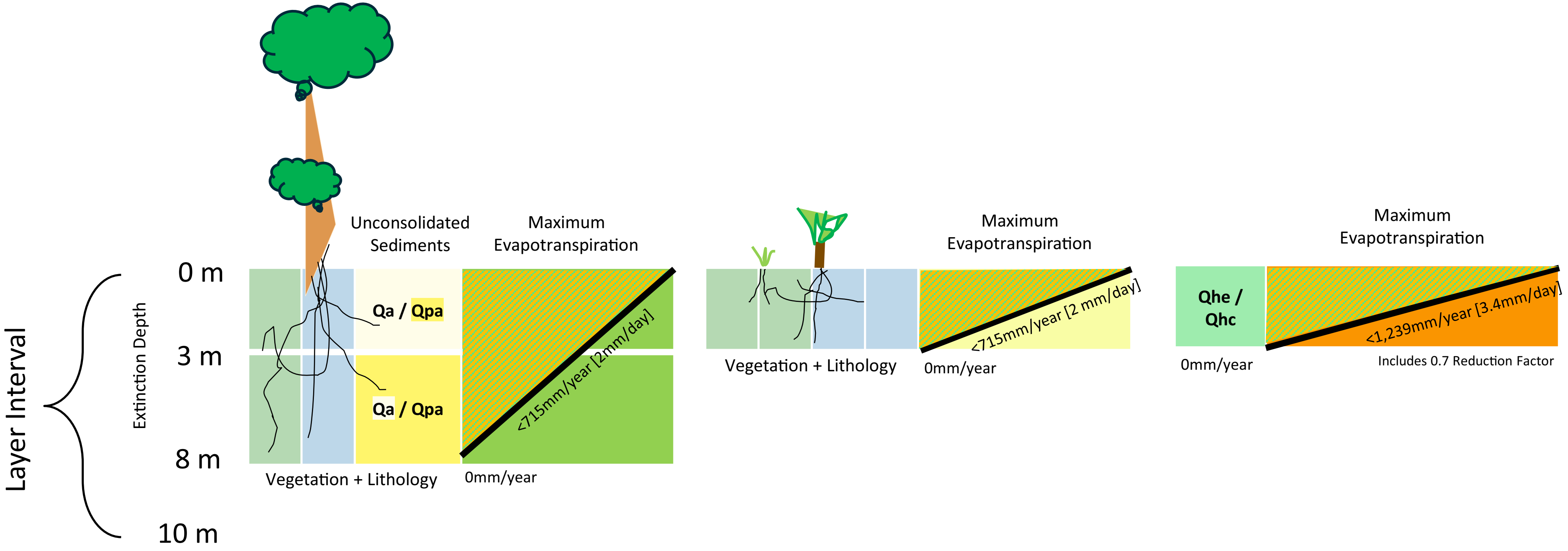


Figure 7-6

Numerical Groundwater Flow Model – Maximum Rate (and Extinction Depths) of Evapotranspiration Schematic

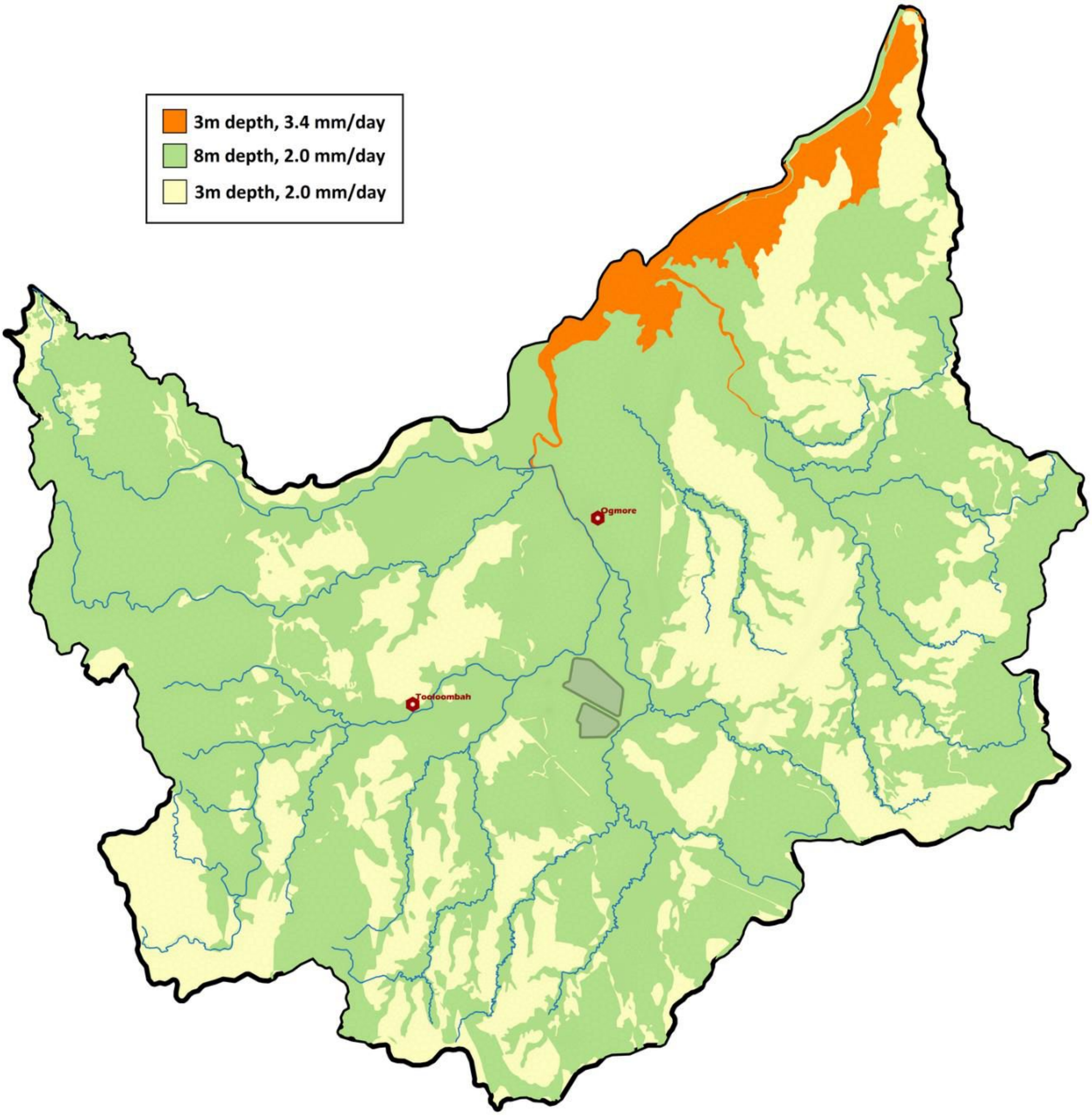
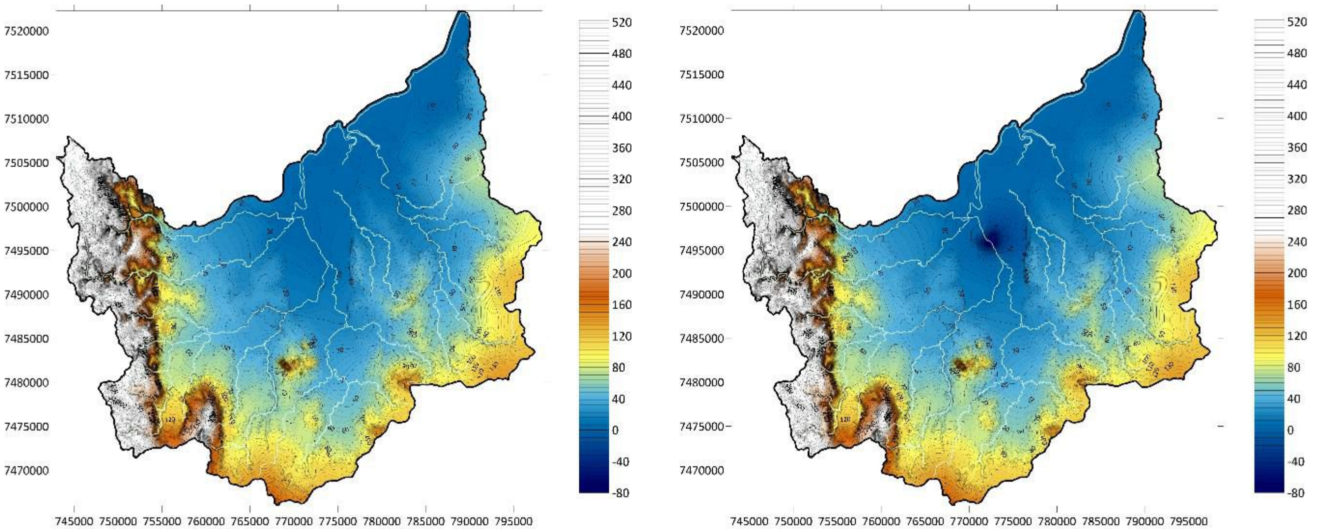


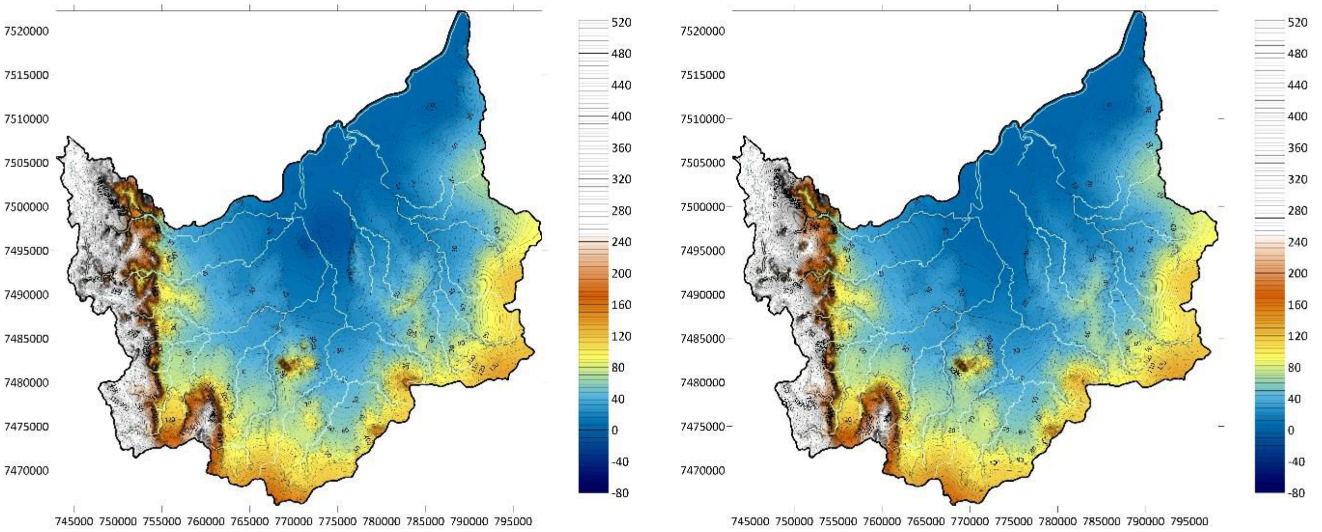
Figure 7-7

Numerical Groundwater Flow Model – Maximum Rate (and Extinction Depths) of Evapotranspiration Applied Across Model Domain



[a] 1919 – Pre-Mining (Bowman & Ogmore)

[b] 1964 – End of Mining (Bowman & Ogmore)



[c] 1969 – Post-Mining Recovery [5 Years]

[d] 2019 – Post-Mining Recovery (55 Years)

Figure 7-8

Pre-Calibration Model Run – Groundwater Levels [mAHD]

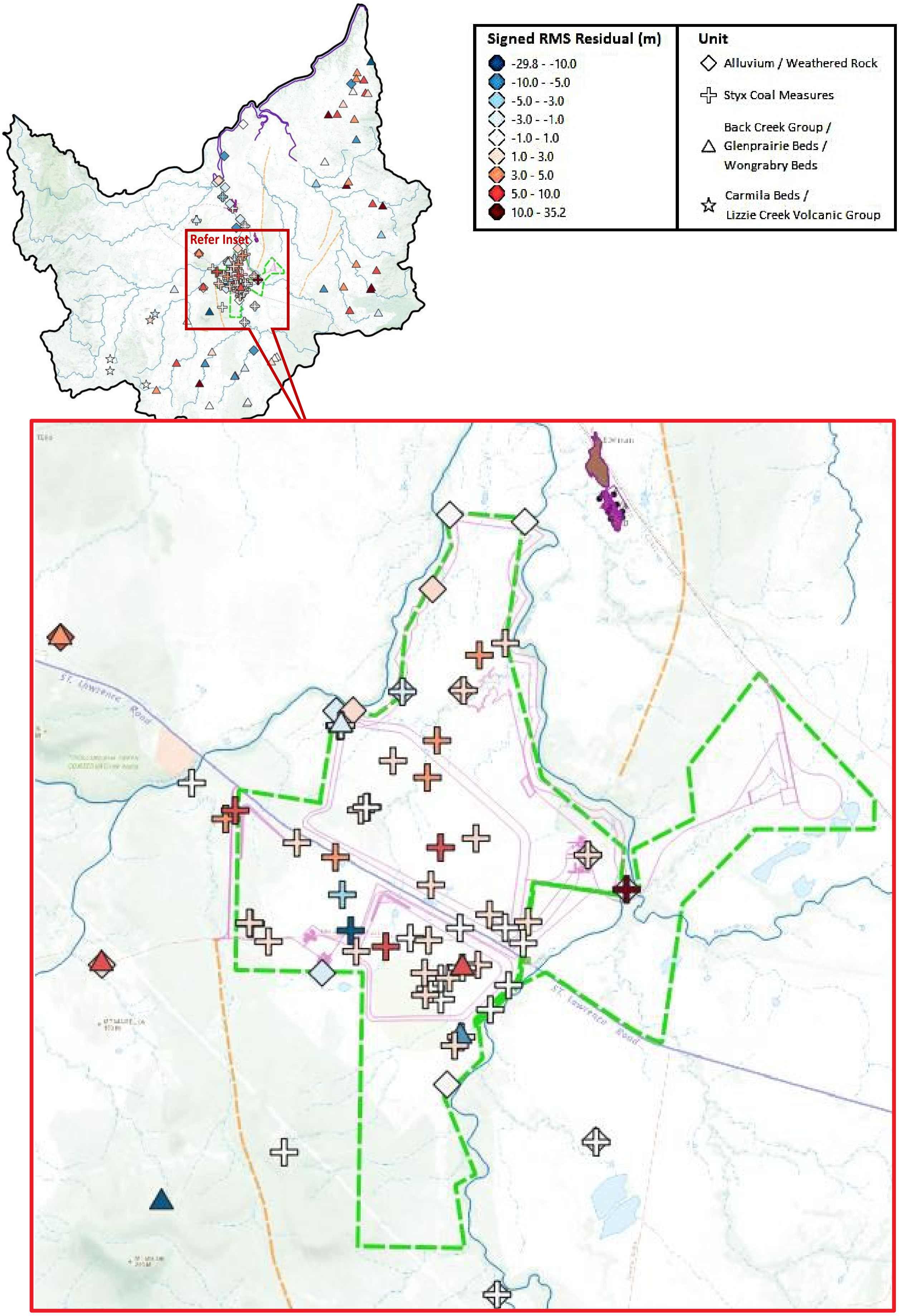


Figure 7-9

Calibration Model Results – All Target Residuals (m)

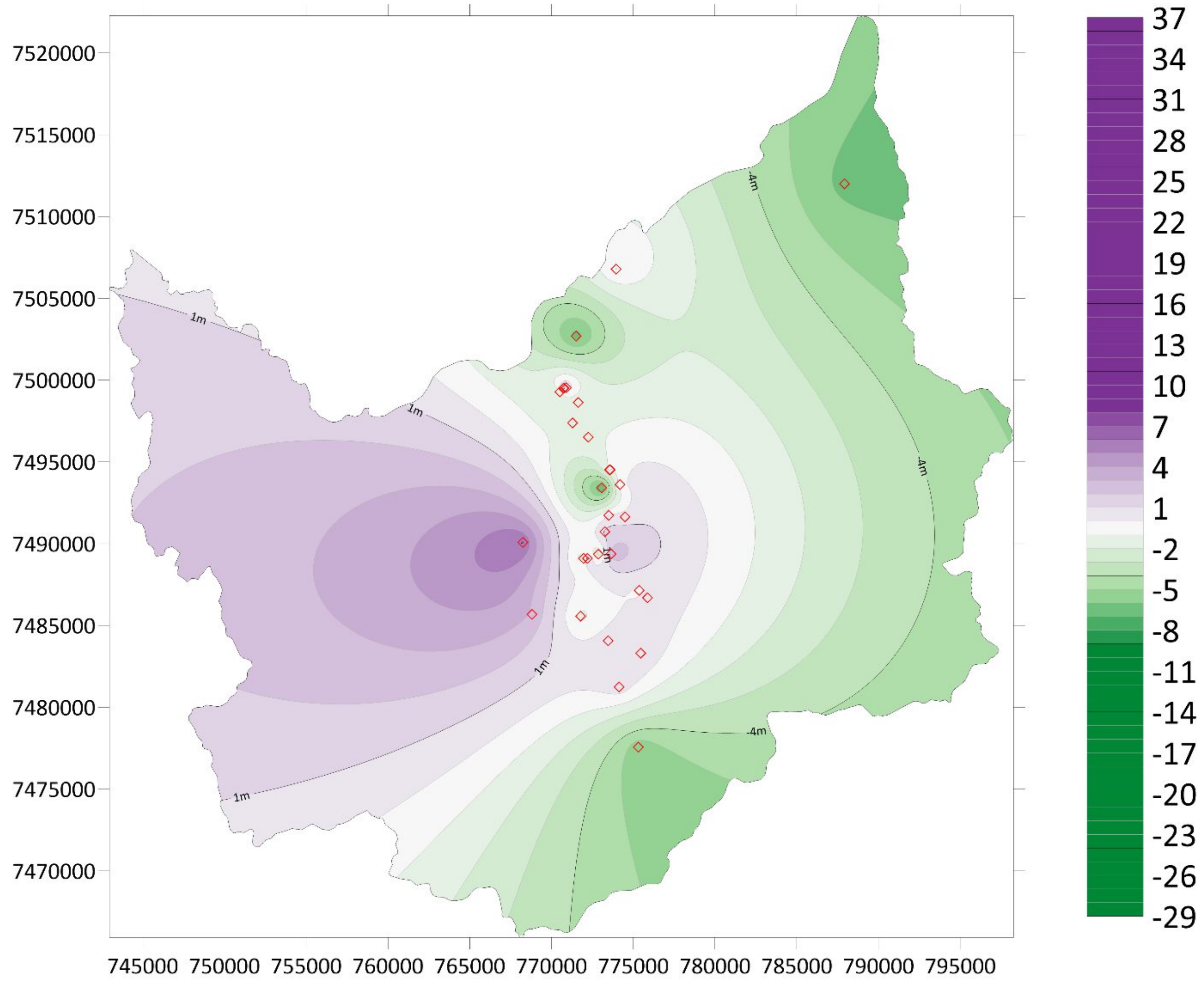


Figure 7-10[a]

Calibration Model Results – Extrapolated Residuals
[Cenozoic Deposits / Regolith]

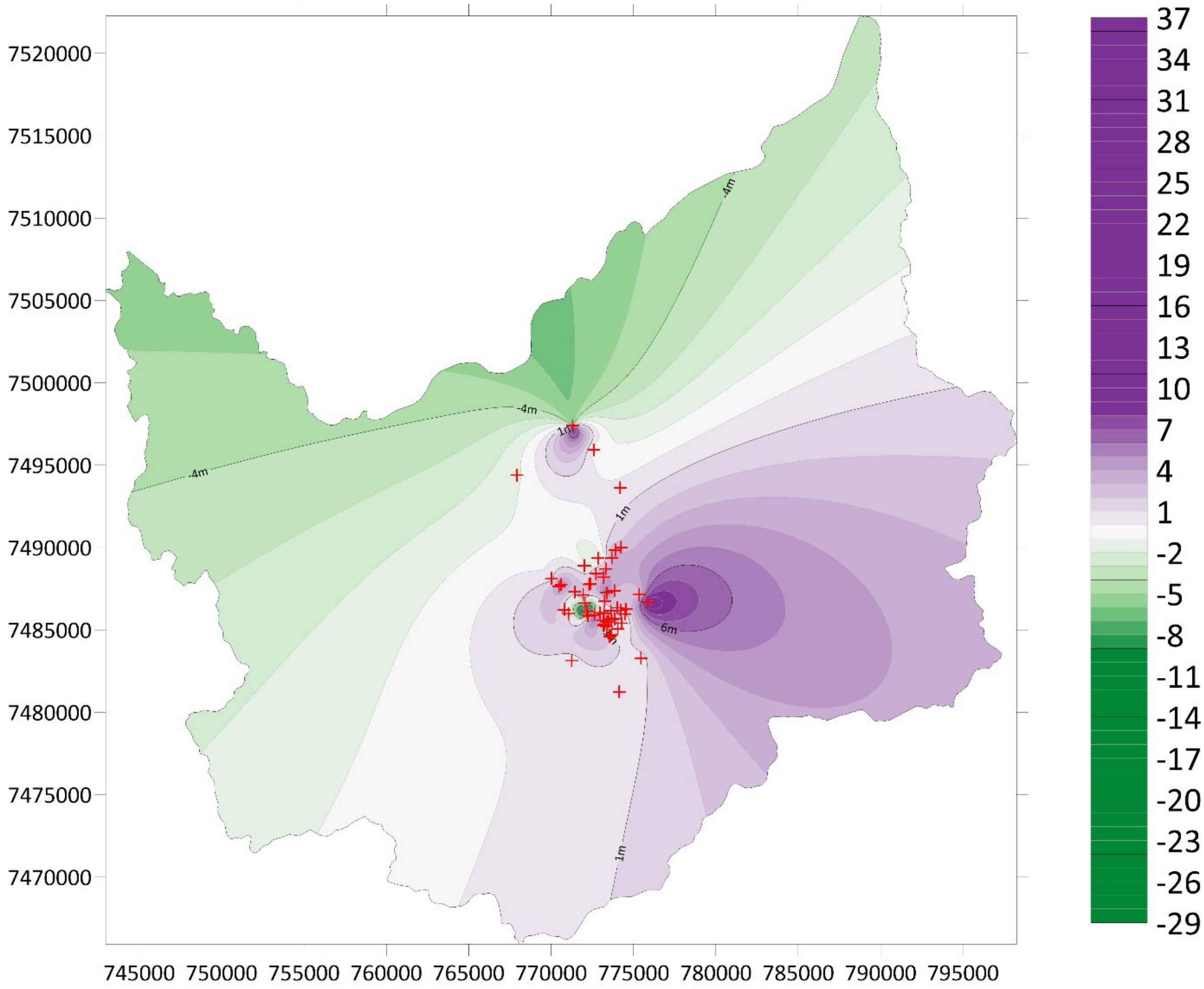


Figure 7-10[b]

Calibration Model Results – Extrapolated Residuals [Styx Coal Measures]

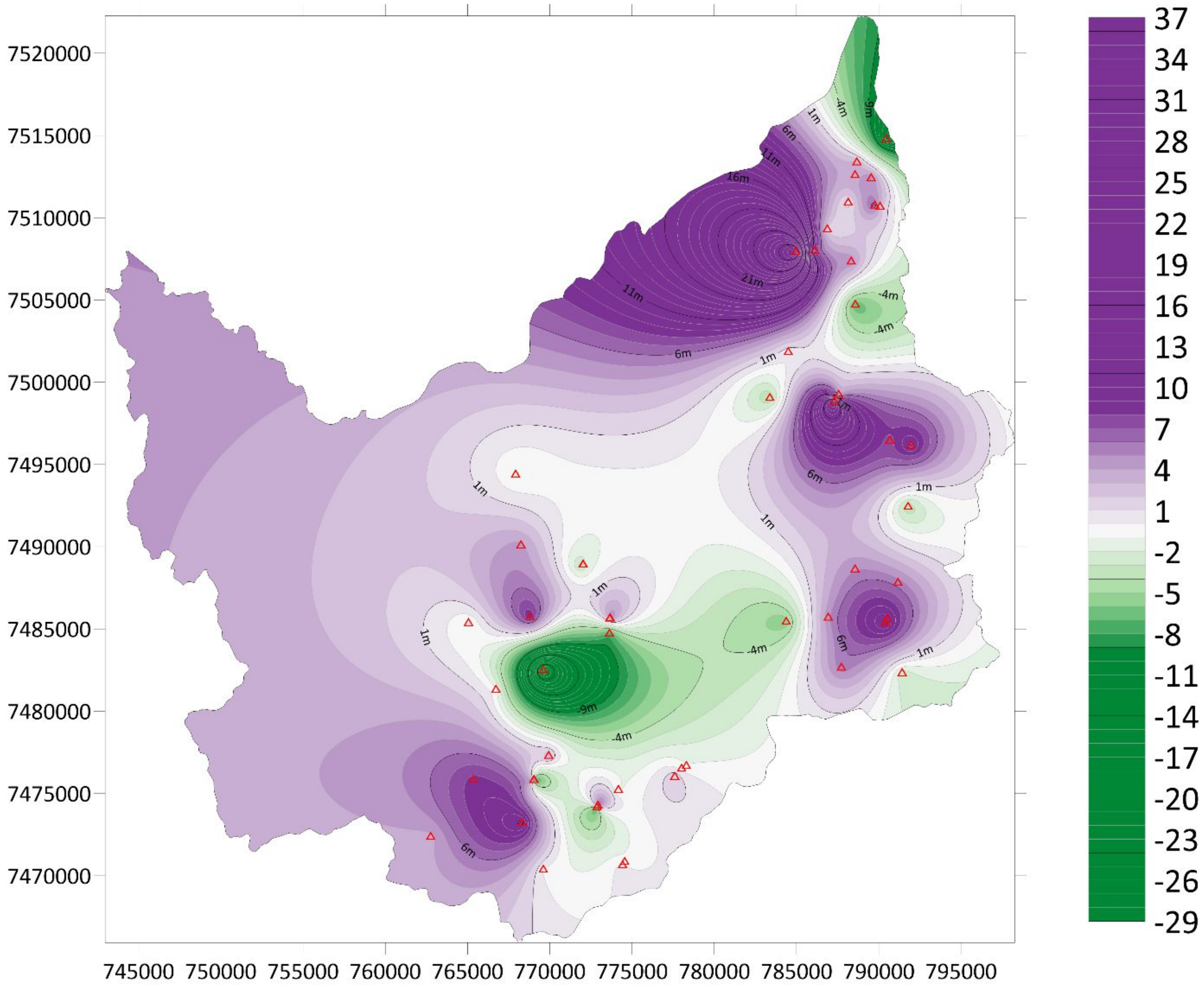


Figure 7-10[c]

Calibration Model Results – Extrapolated Residuals
[Permian Measures and Other Volcanic Units]

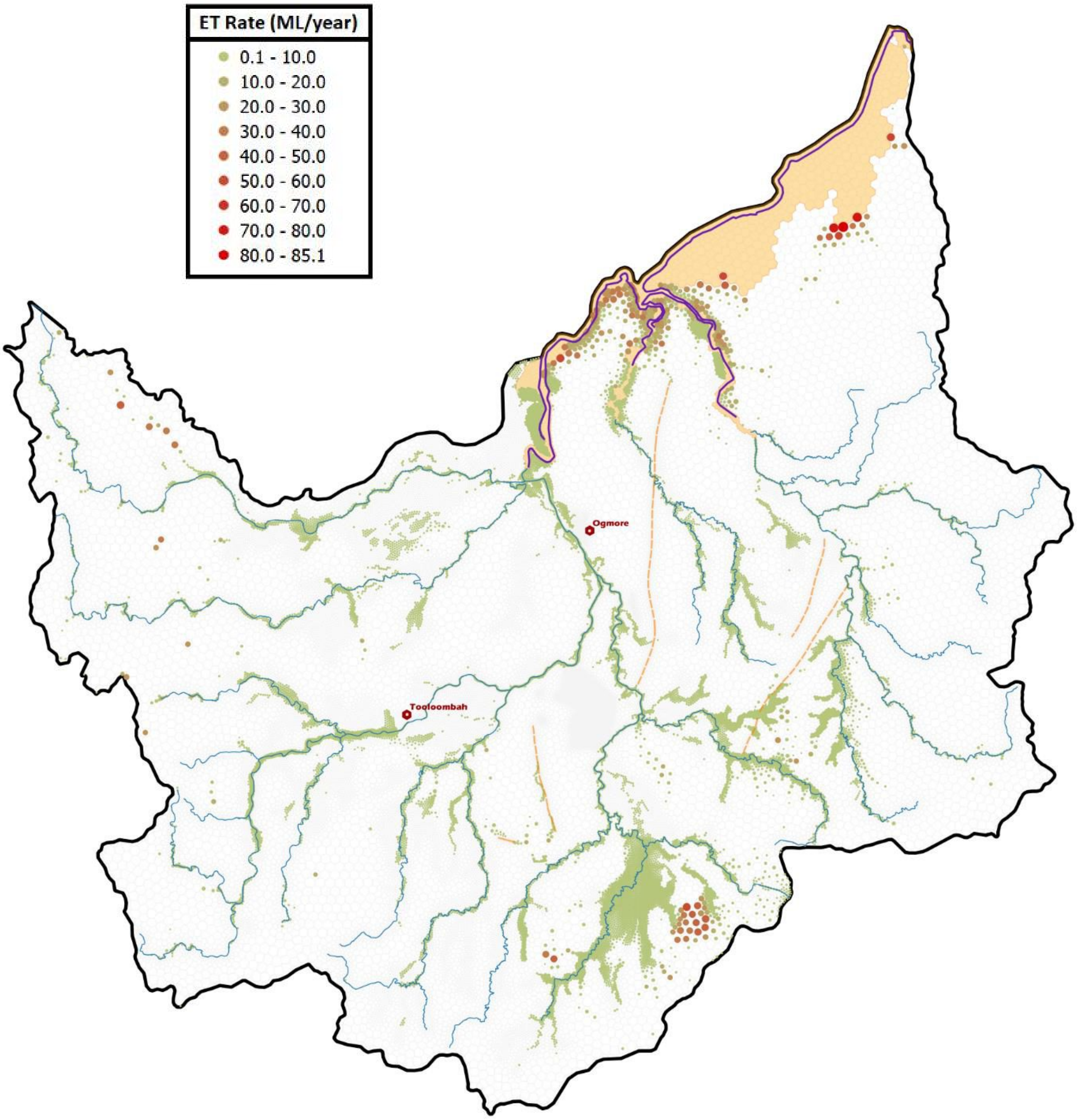
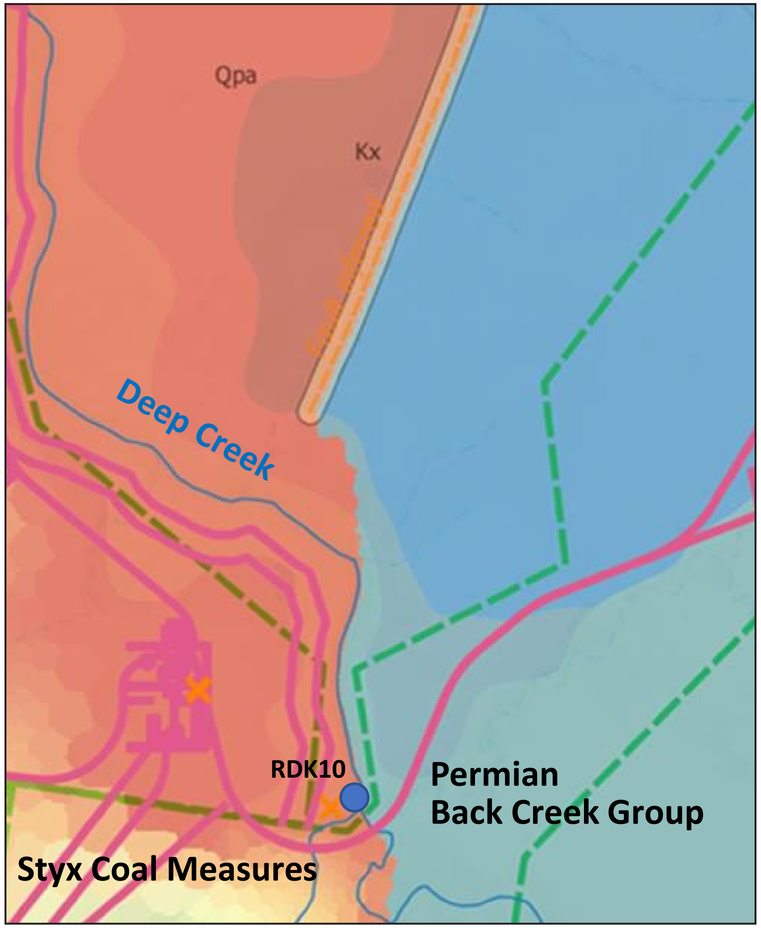
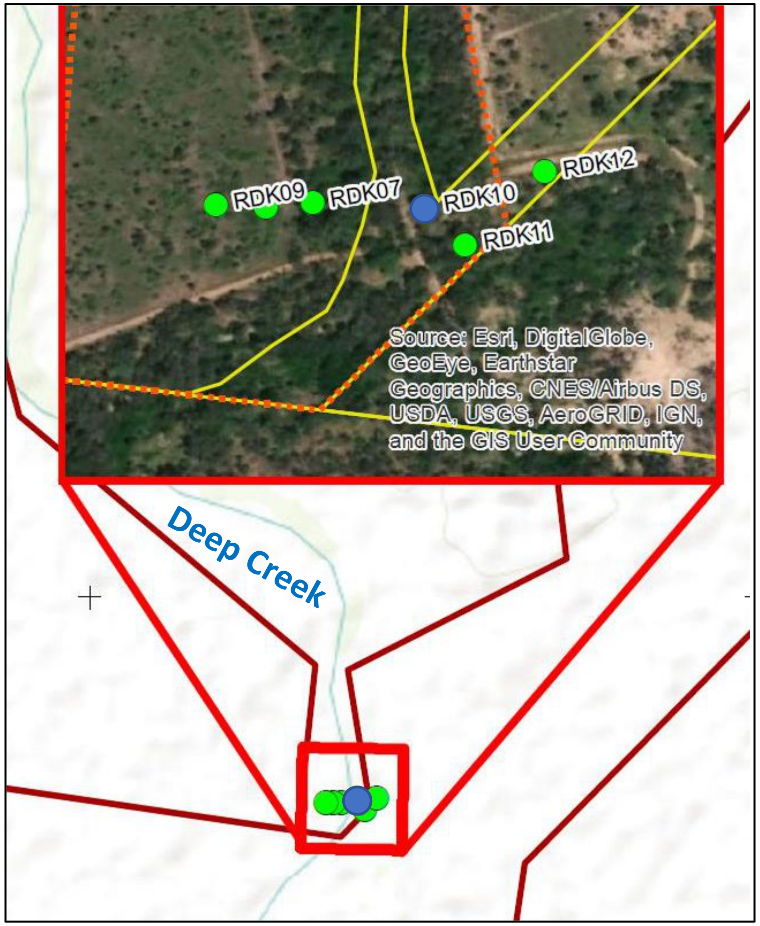


Figure 7-11

Evapotranspiration Flux Across the Model Domain



Numerical Groundwater Model Construct Interface



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

CQCPL Fault Delineation Drilling Validation
April 2020

HA-WAR1_V4_DRAFT_May2020

Figure 7-12

Post Model Construct Fault Validation (RDK7-RDK12)

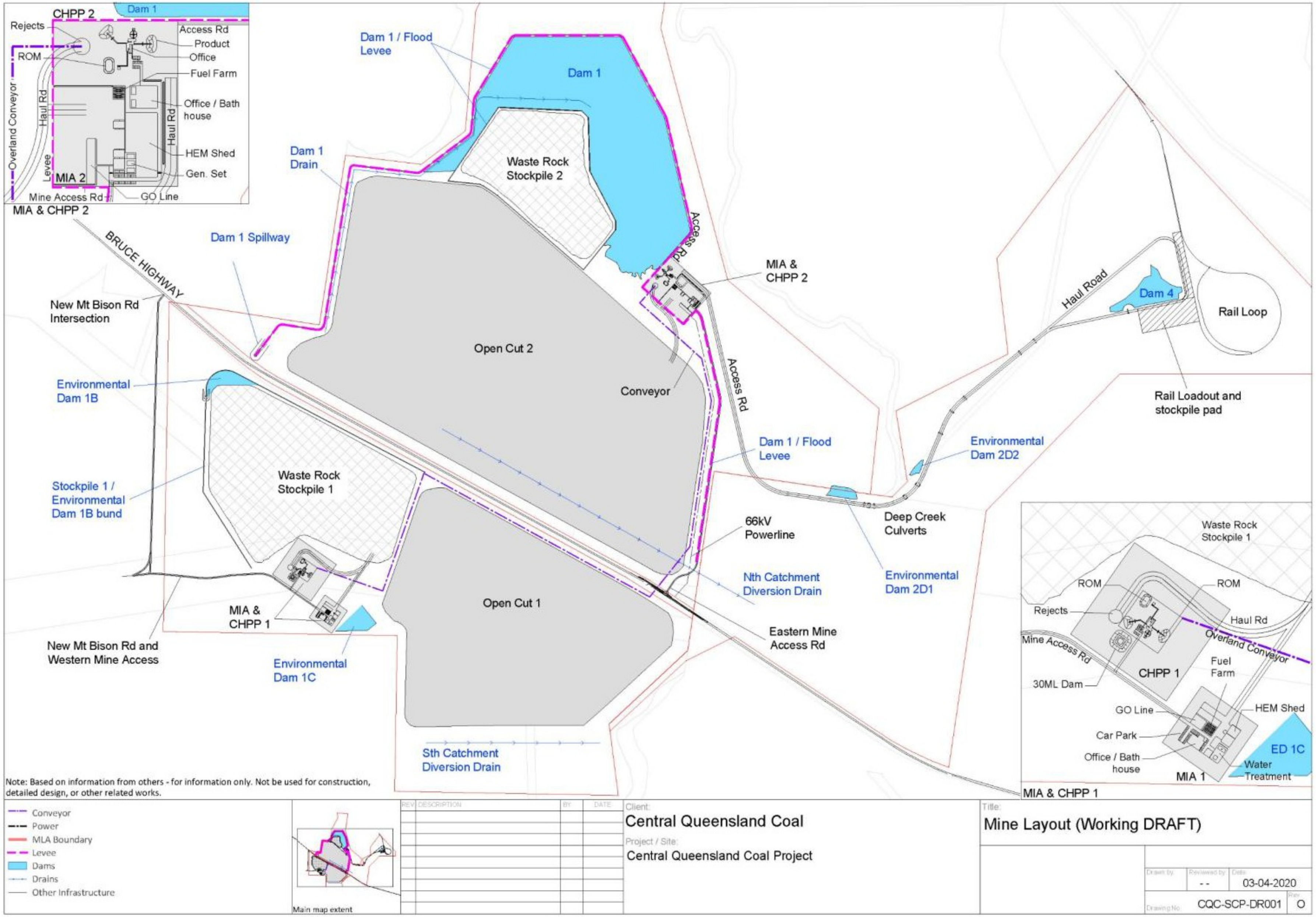


Figure 8-1

Indicative Mine Layout

[*Source: CQCPL, 2020*]

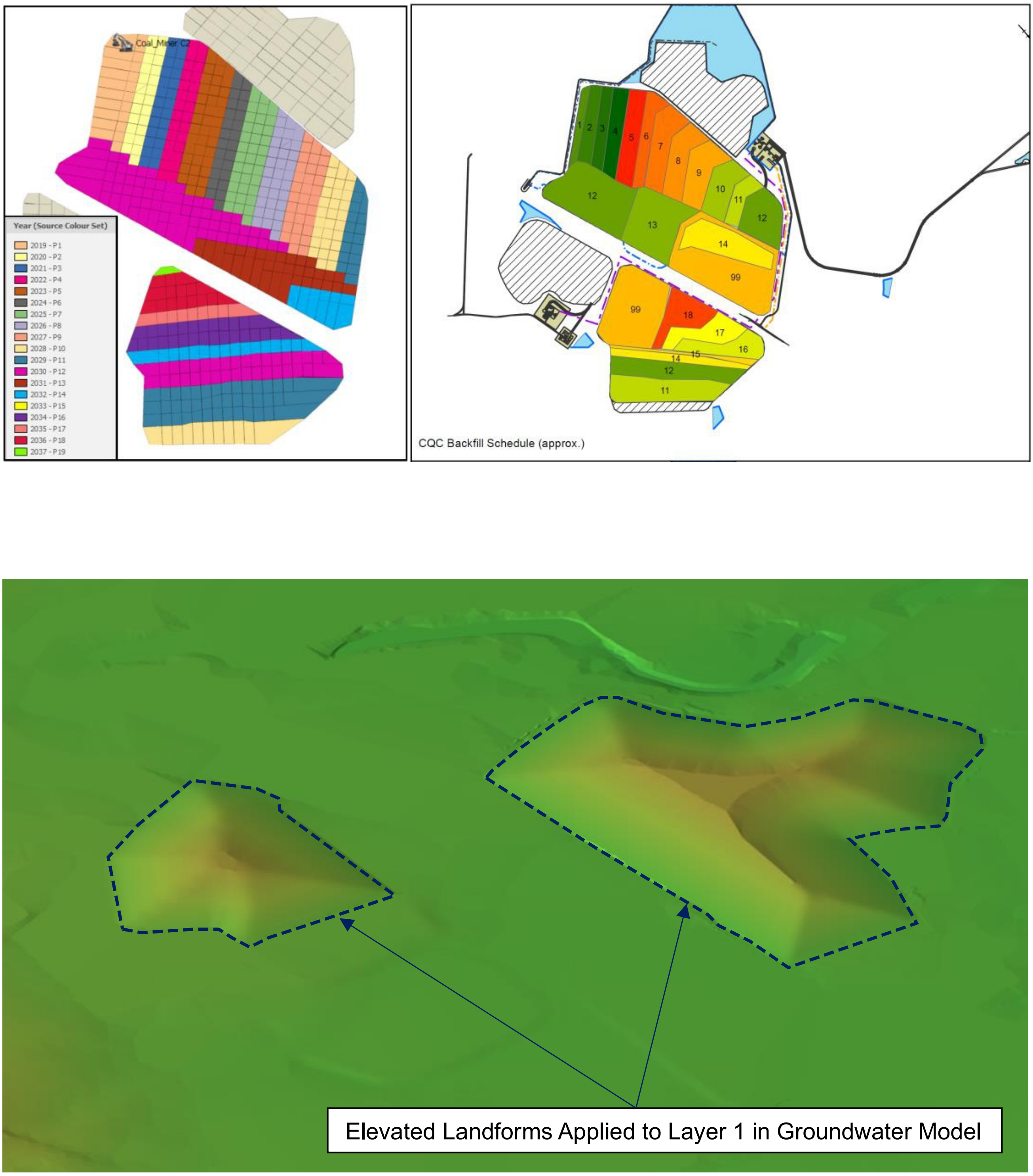
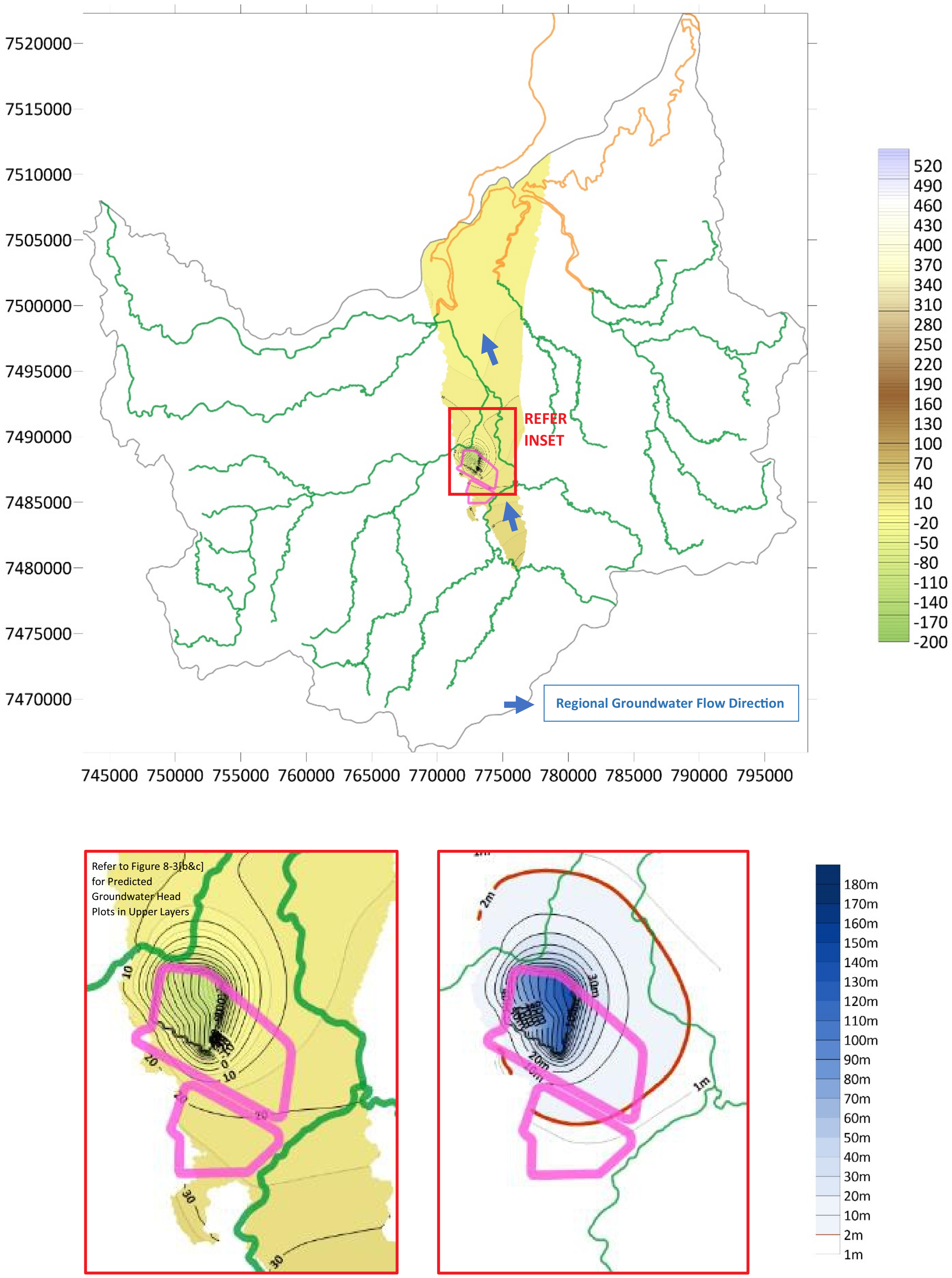


Figure 8-2

Indicative Mine Plan (Periodic) Progression, Backfill (Annual) Sequence [*Source: CQCPL, 2020*] **and Indicative Final Landform Design Surface – LF3** [*with annotation*] [*Source: Xenith Consulting, 2020*]



Refer to Figure 8-3[b&c] for Predicted Groundwater Head Plots in Upper Layers

Figure 8-3(a)

Model Predicted Drawdown and Head Plots After 3 Years of Mining – Styx Coal Measures (Layer 8)

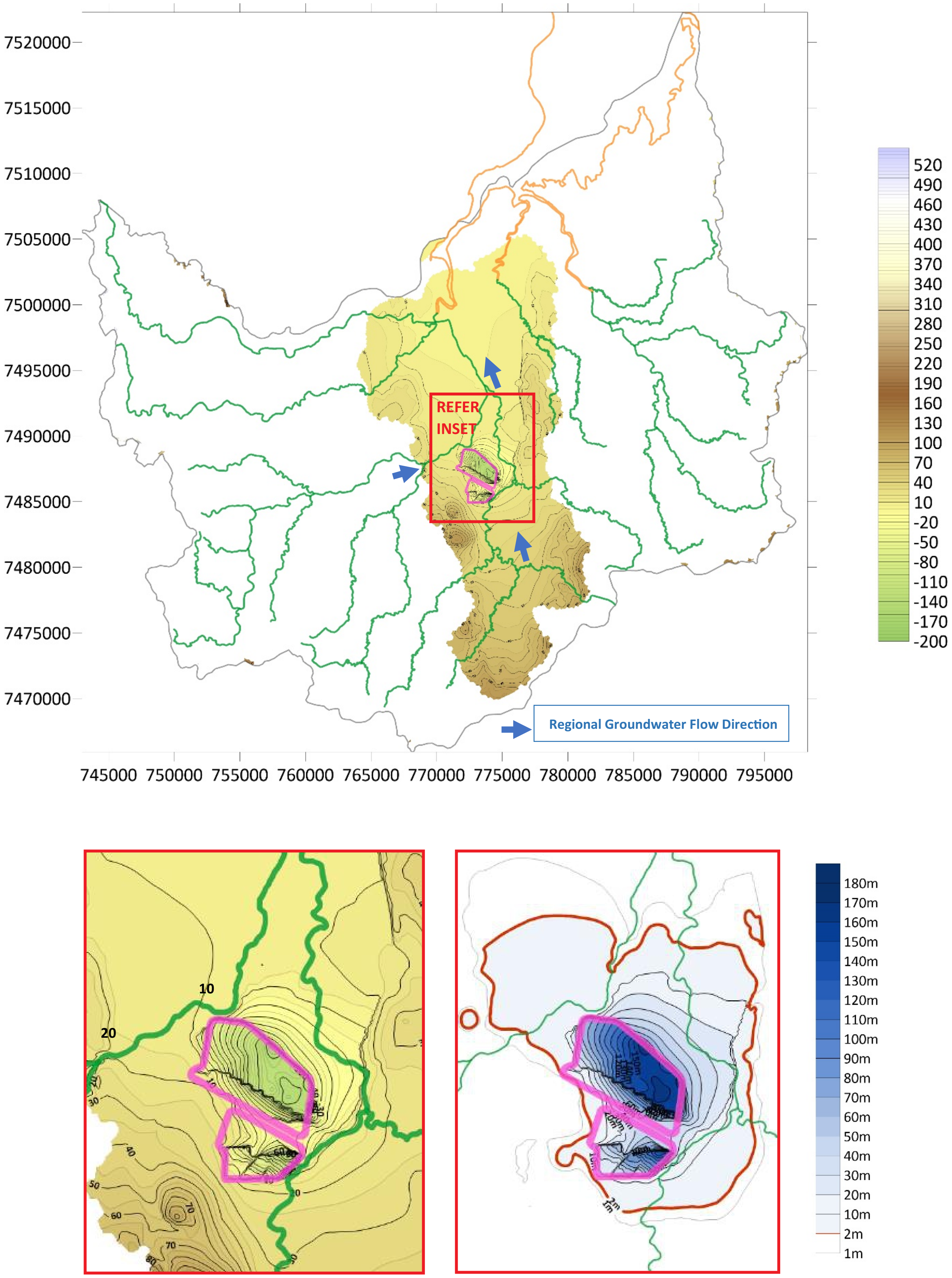


Figure 8-3(b)

Model Predicted Drawdown and Head Plots After 10 Years of Mining – Cenozoic Deposits [Lower] / Regolith (Layer3)

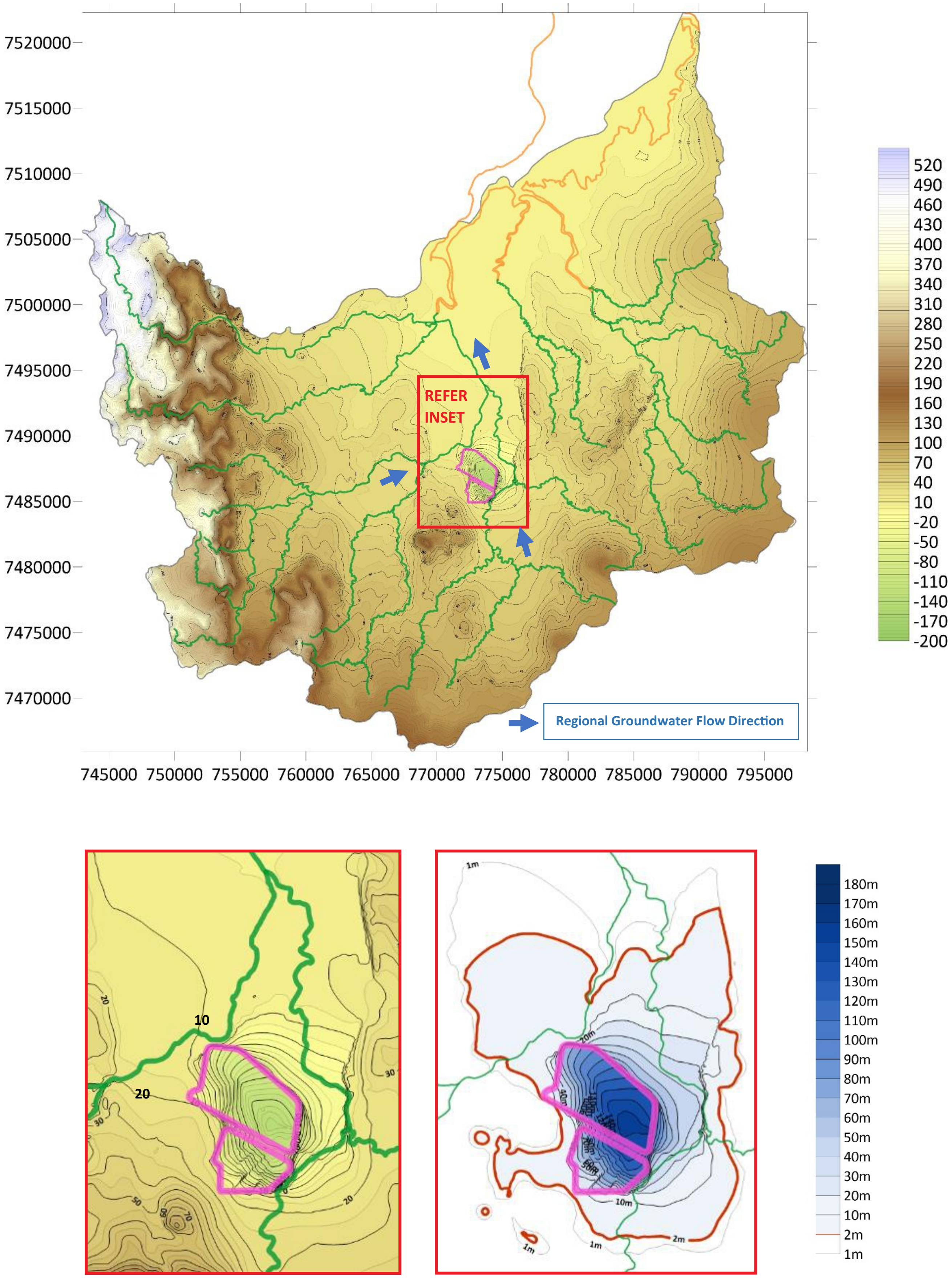


Figure 8-3(c)

Model Predicted Drawdown and Head Plots at End of Mining (Prior to Final Backfill) - Cenozoic Deposits [Upper] / Regolith (Layer 2)

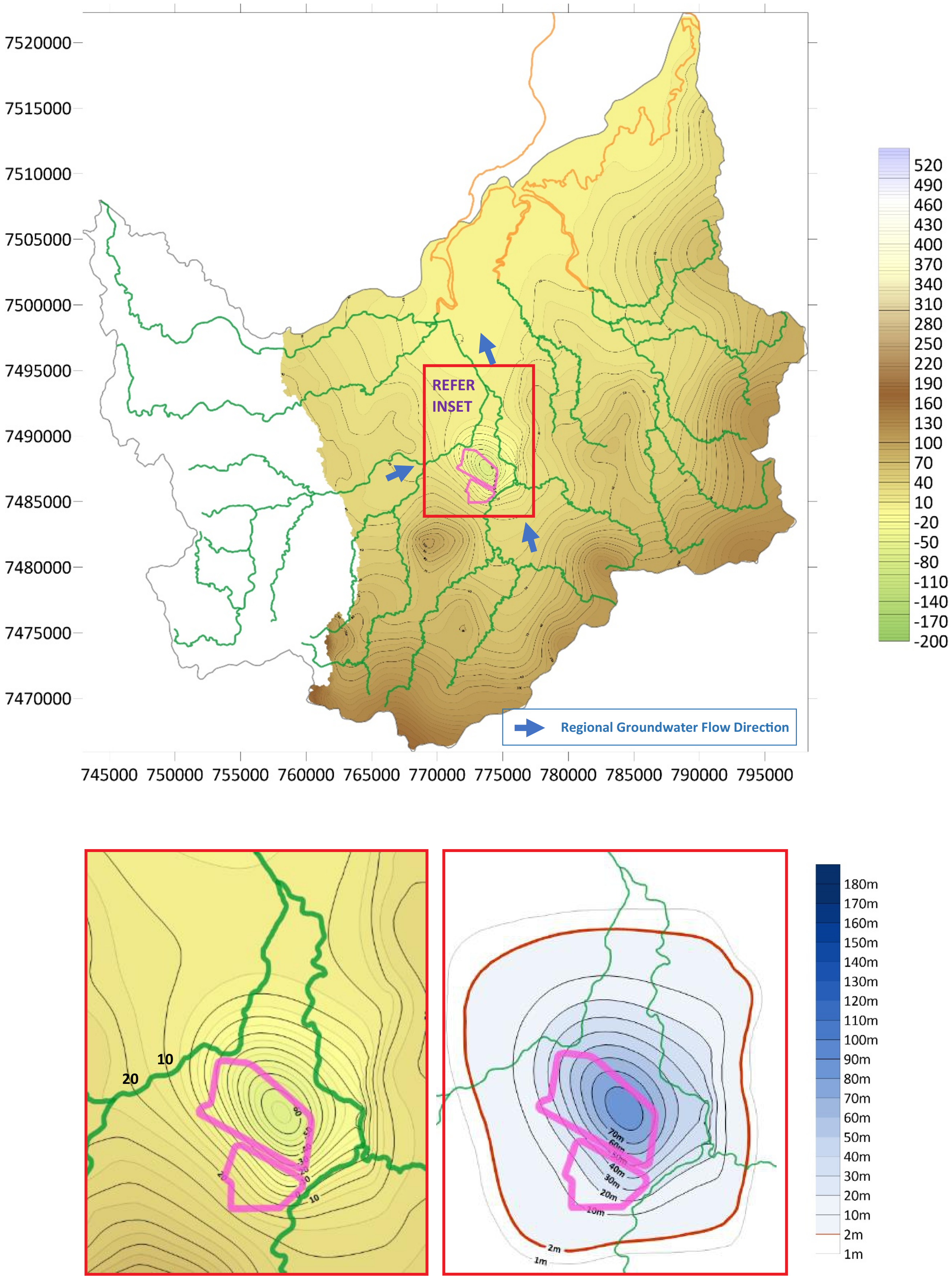


Figure 8-3(d)

Model Predicted Drawdown and Head Plots at End of Mining (Prior to Final Backfill) - Back Creek Group (Layer 12)

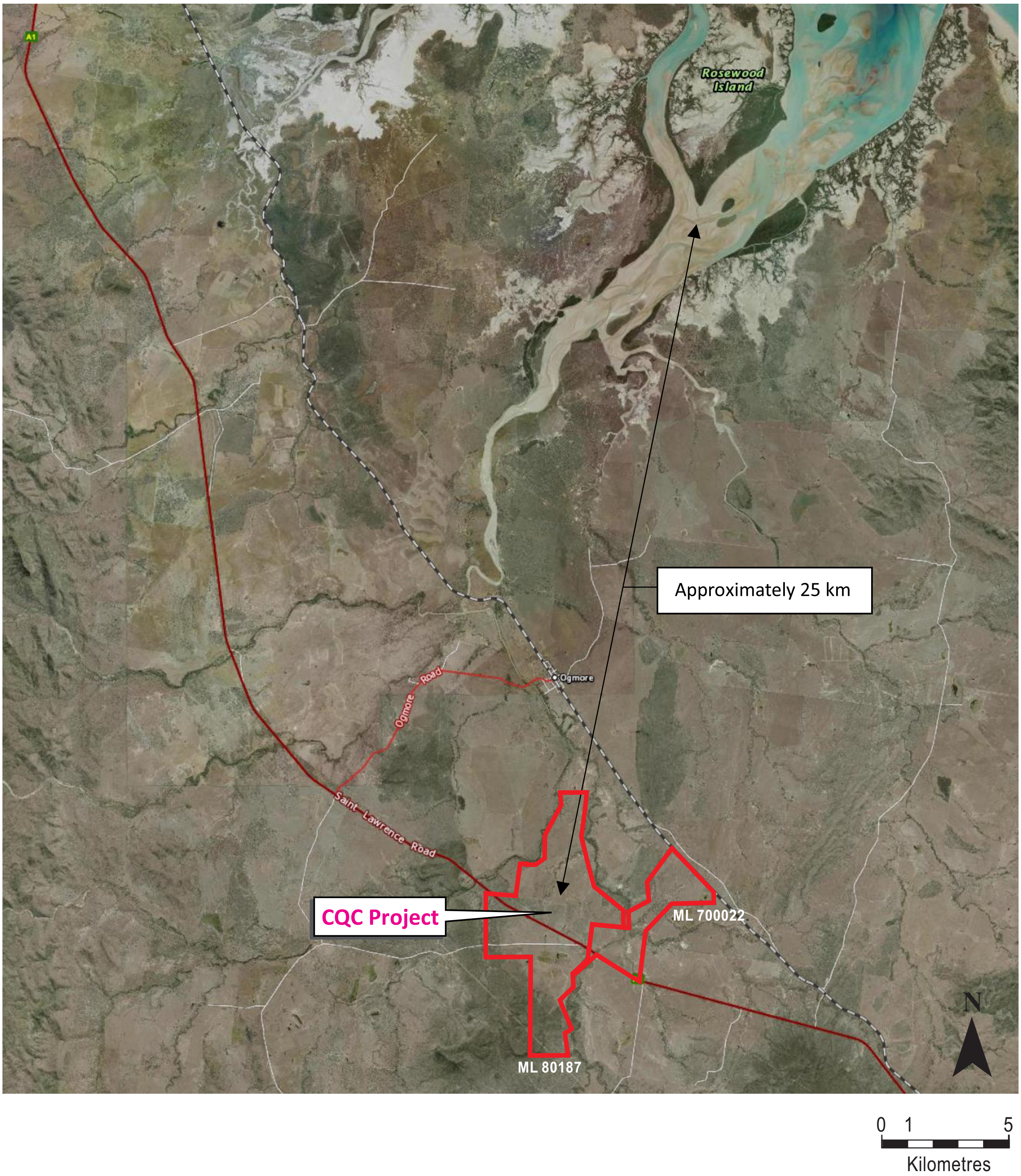
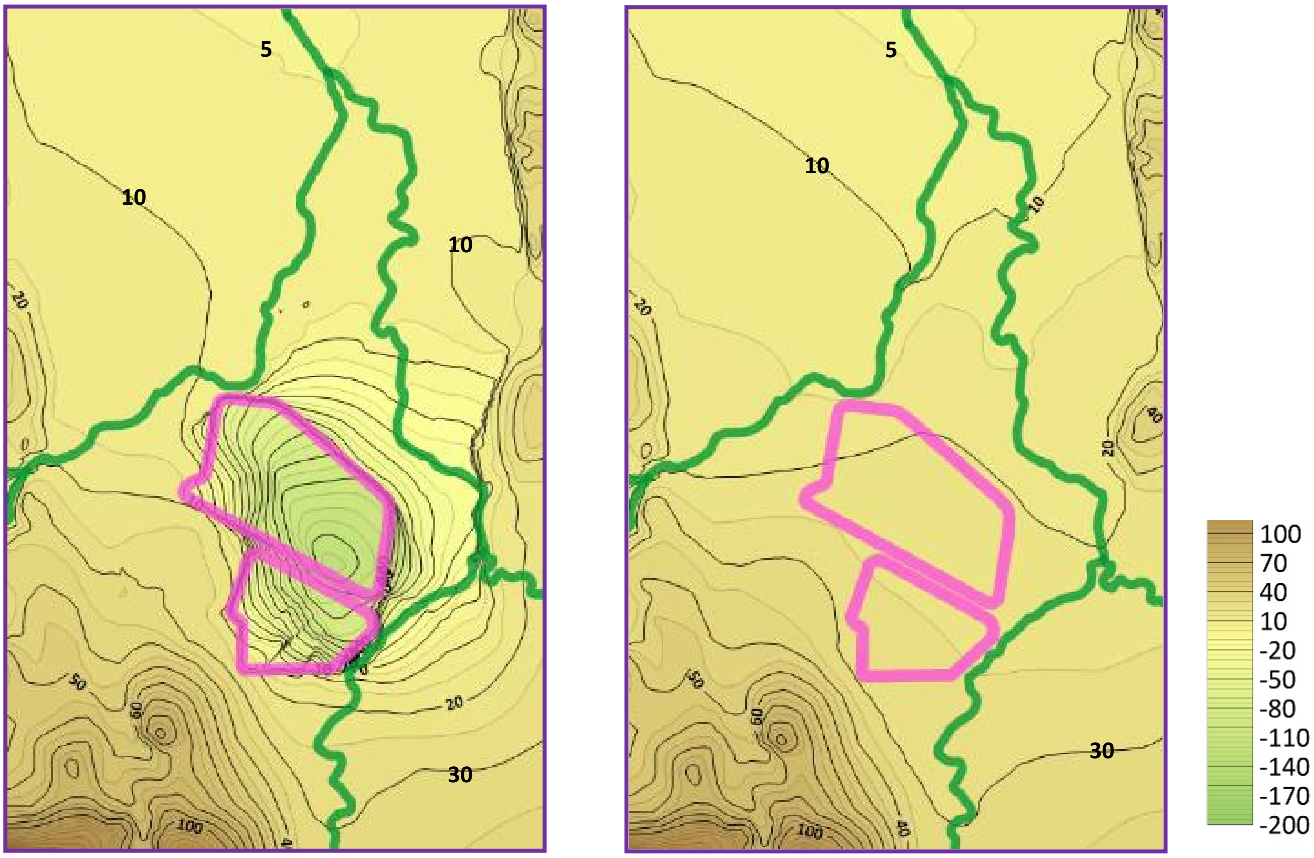


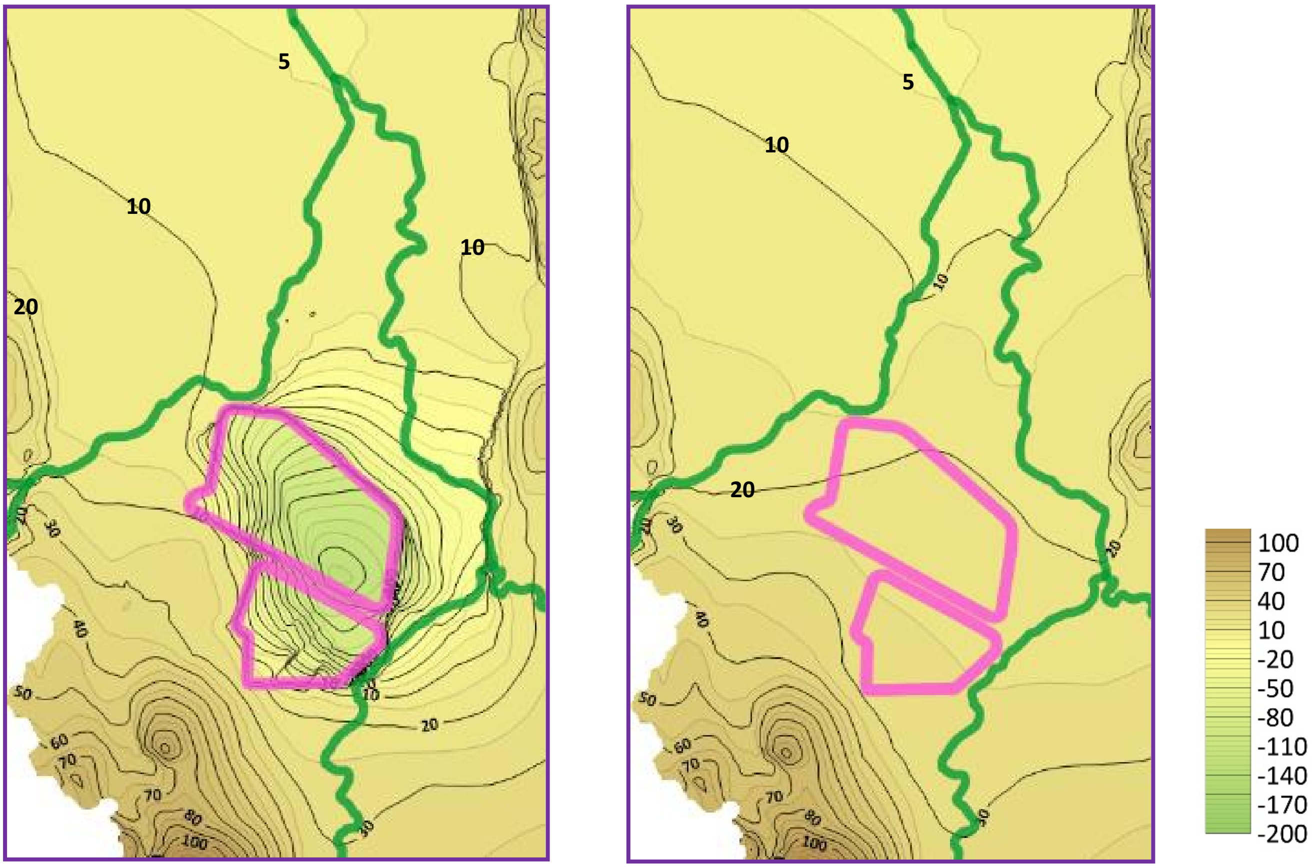
Figure 8-4

Aerial Photograph – Styx River Mouth and Rosewood Island [*with annotation*]
[*Source: State of Queensland, 2020*]



Layer 2 [i] Approximately 5 Years Post-Mining

Layer 2 [ii] Long Term Recovery [mAHD]

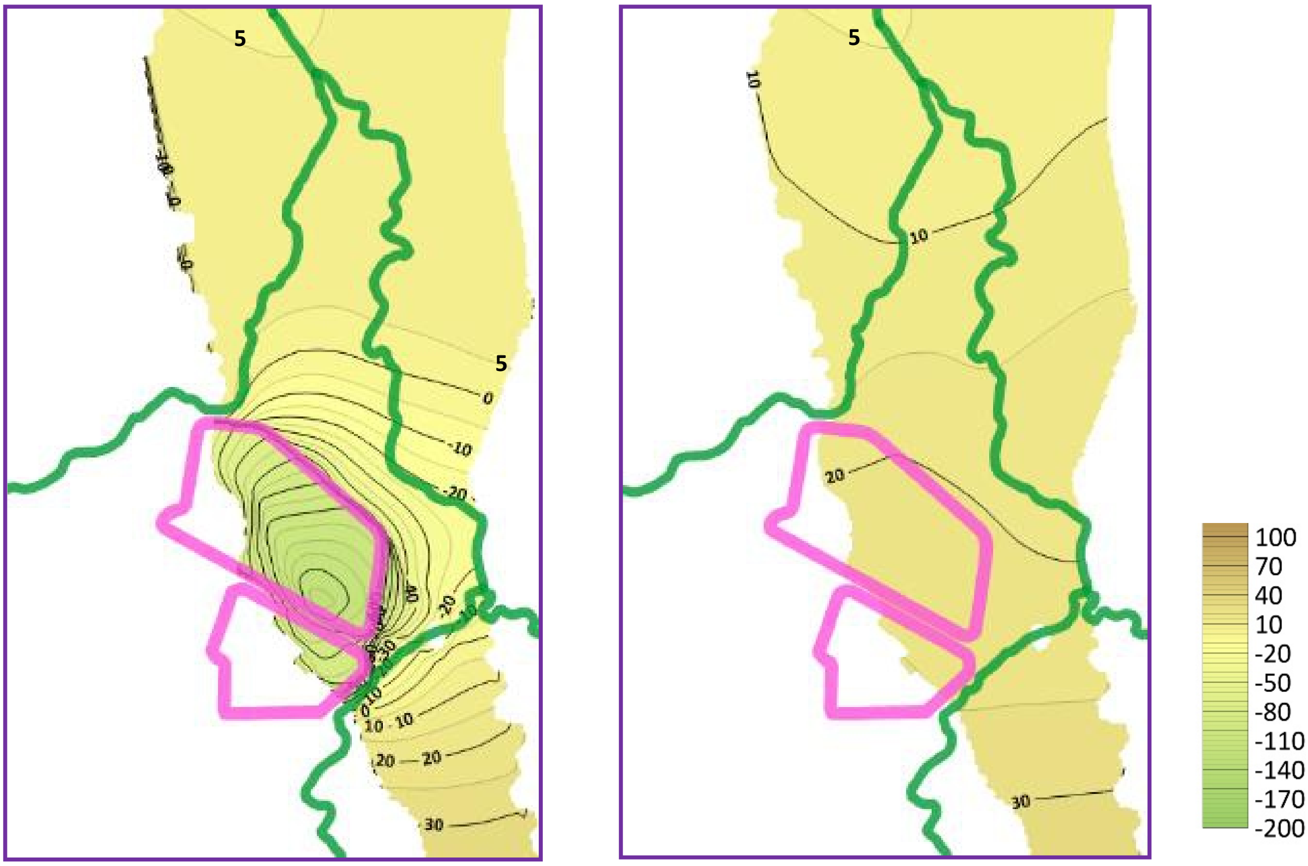


Layer 3 [i] Approximately 5 Years Post-Mining

Layer 3 [ii] Long Term Recovery [mAHD]

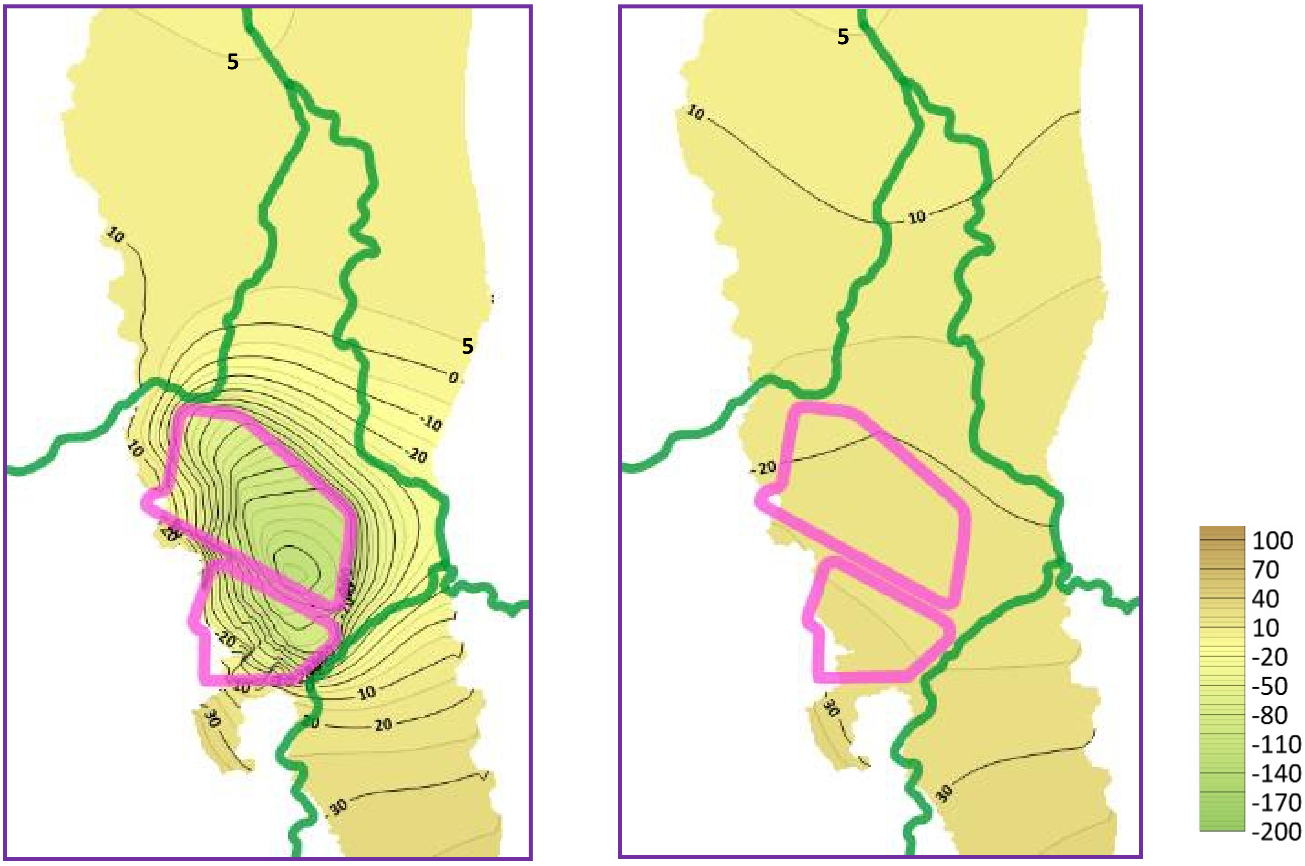
Figure 8-5(a)

Model Predicted Head Plots Post-Mining Recovery - Cenozoic Deposits / Regolith (Layers 2 and 3)



Layer 5 [i] Approximately 5 Years Post-Mining

Layer 5 [ii] Long Term Recovery [mAHD]

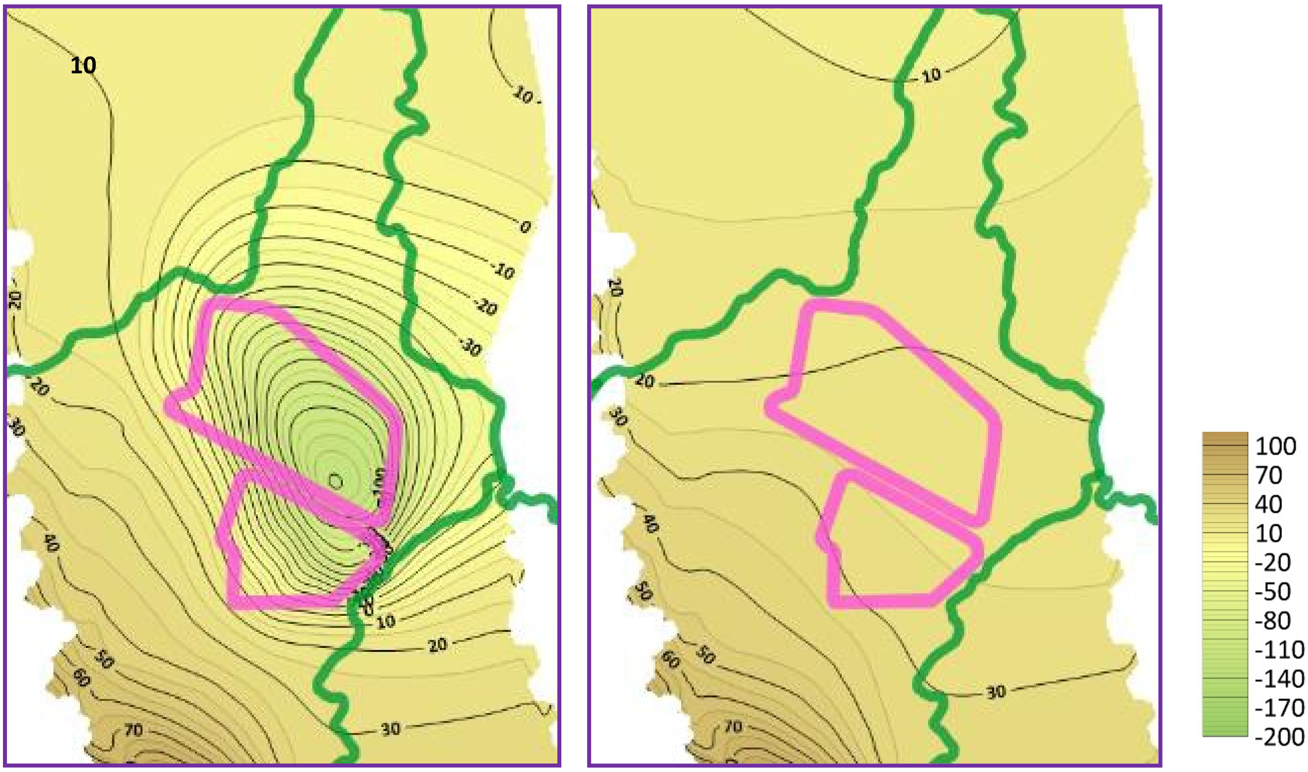


Layer 8 [i] Approximately 5 Years Post-Mining

Layer 8 [ii] Long Term Recovery [mAHD]

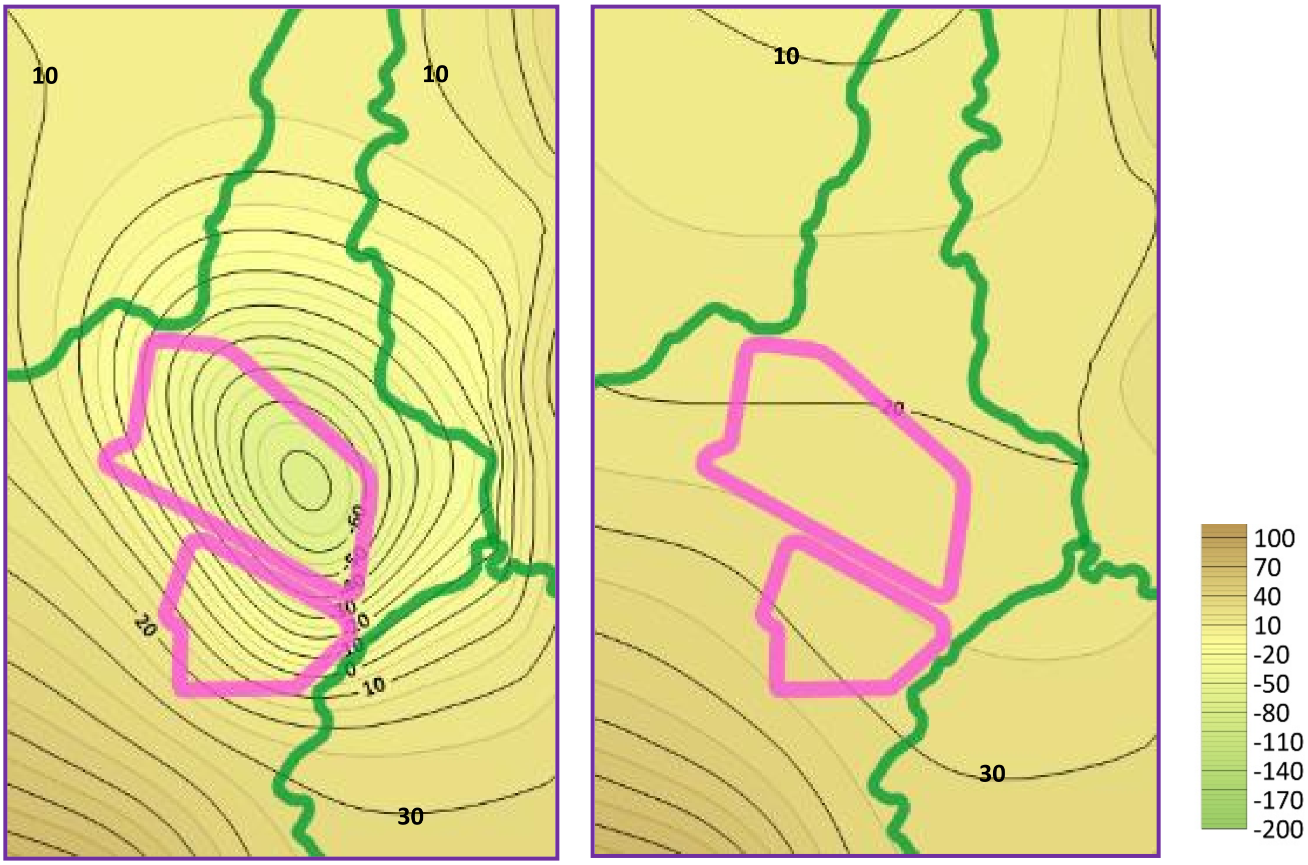
Figure 8-5(b)

Model Predicted Head Plots Post-Mining Recovery - Styx Coal Measures (Layers 5 and 8)



Layer 11 [i] Approximately 5 Years Post-Mining **Layer 11 [ii] Long Term Recovery [mAHD]**

-



Layer 12 [i] Approximately 5 Years Post-Mining **Layer 12 [ii] Long Term Recovery [mAHD]**

Figure 8-5(c)

Model Predicted Head Plots Post-Mining Recovery - Styx Coal Measures Underburden (Layer 11) and Back Creek Group (Layer 12)

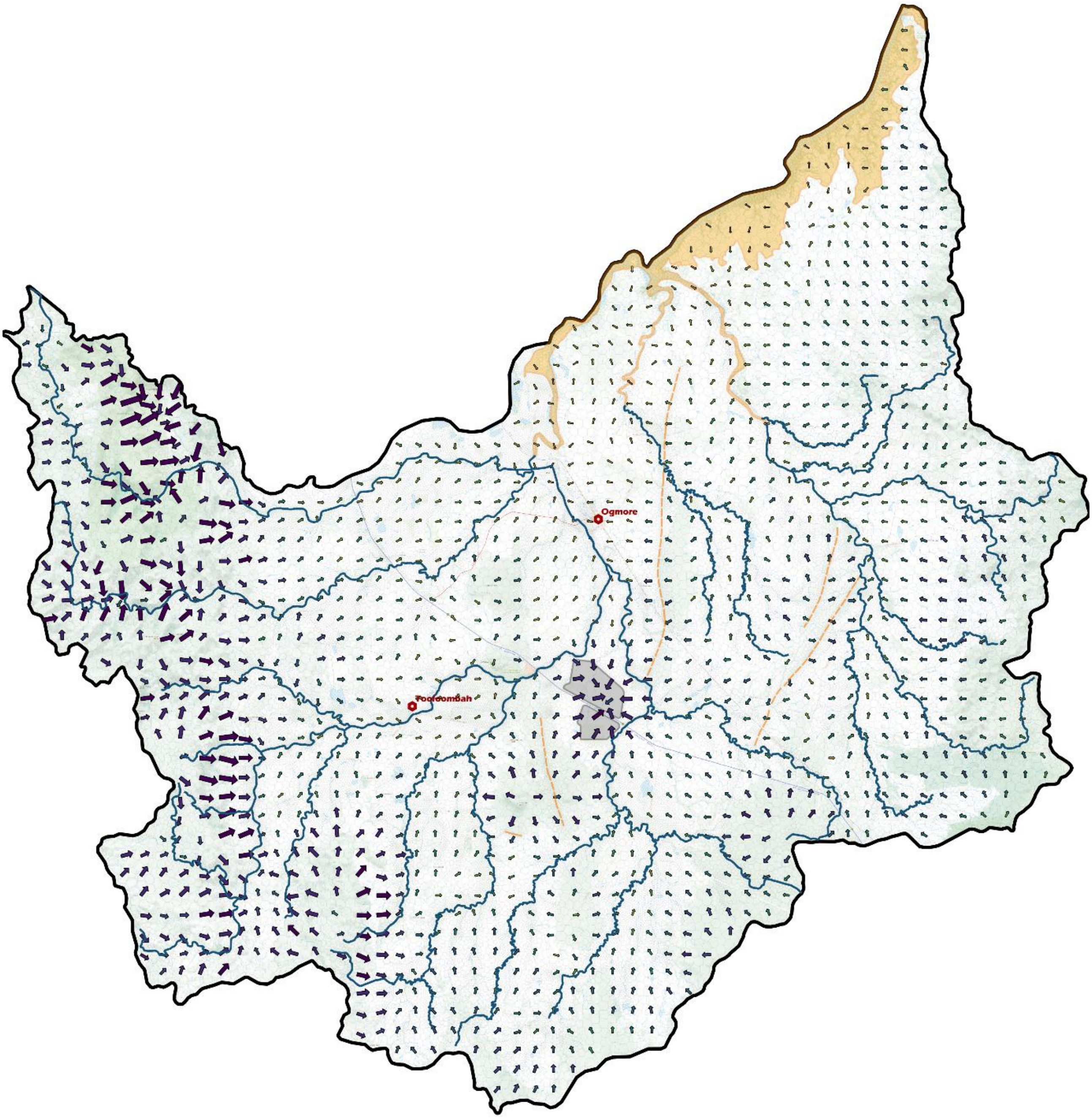


Figure 8-6(a)

Post-Mining [+5 Years (Approximate)] Head Gradients (Flow Direction) in Cenozoic Deposits/Regolith (Layer 2)

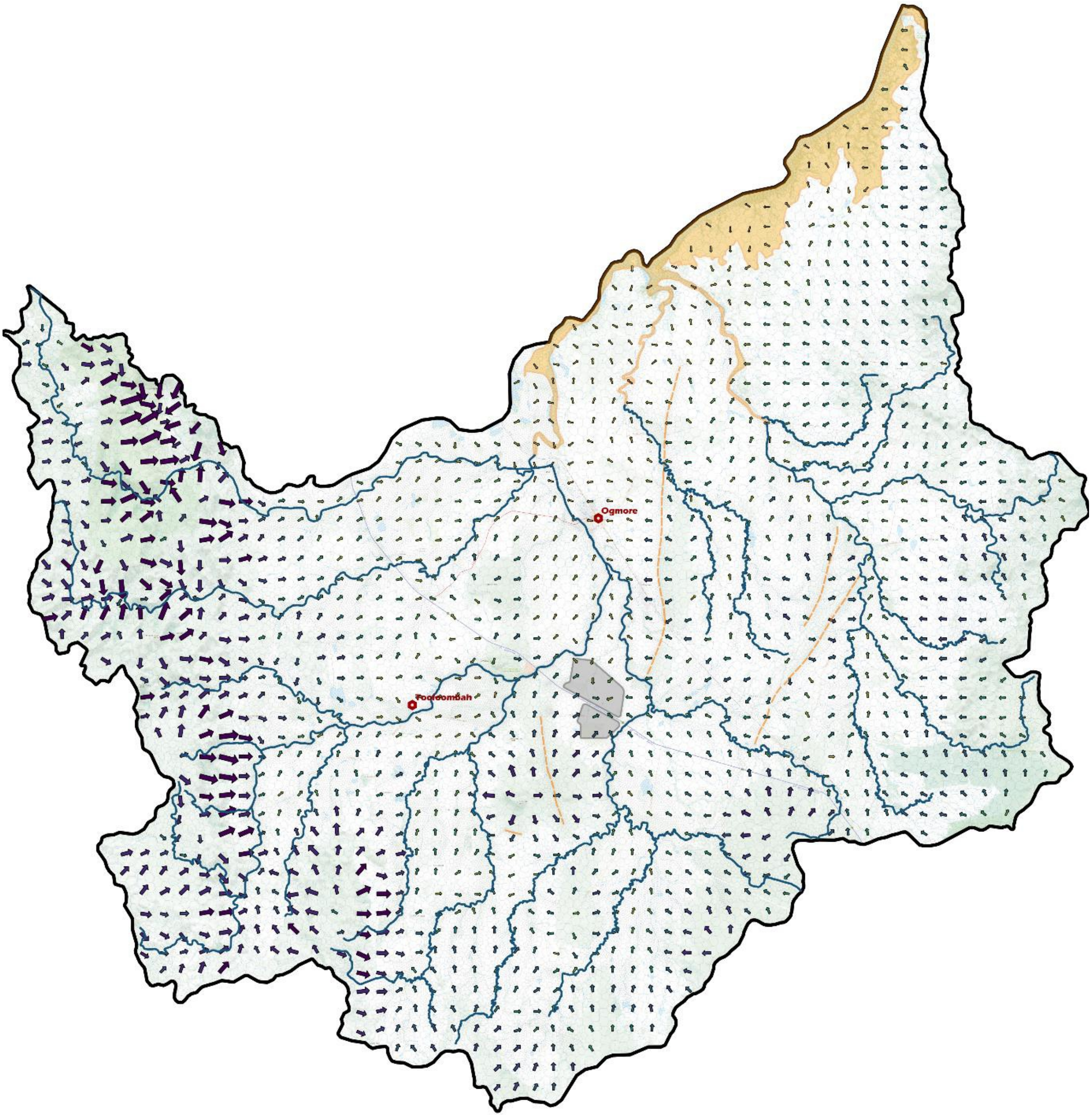


Figure 8-6(b)

Post-Mining [+100 Years (Approximate)] Head Gradients (Flow Direction) in Cenozoic Deposits/Regolith (Layer 2)

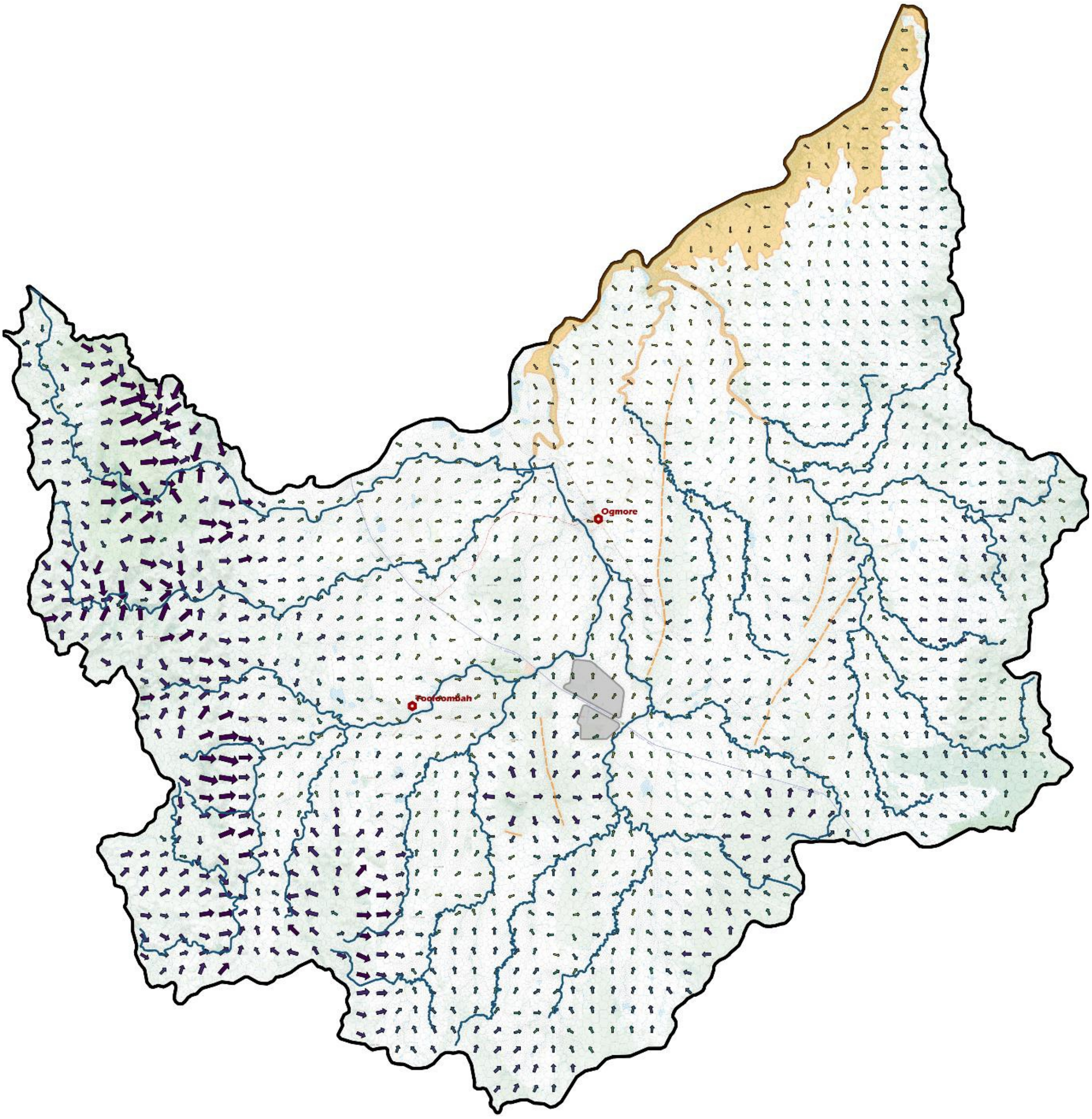


Figure 8-6(c)

Post-Mining [+500 Years (Approximate)] Head Gradients (Flow Direction) in Cenozoic Deposits/Regolith (Layer 2)

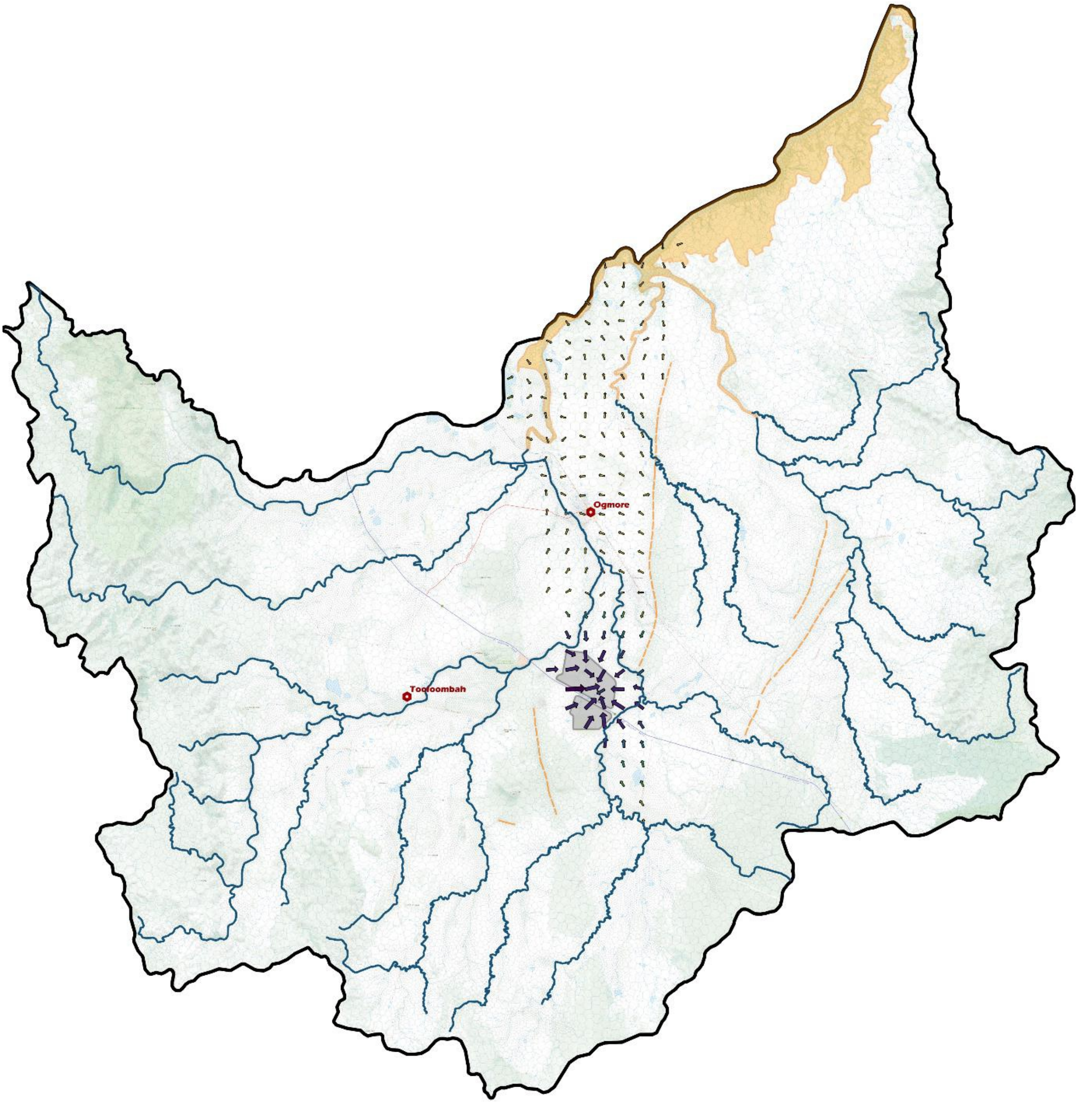


Figure 8-6(d)

Post-Mining [+5 Years (Approximate)] Head Gradients (Flow Direction) in Styx Coal Measures (Layer 8)

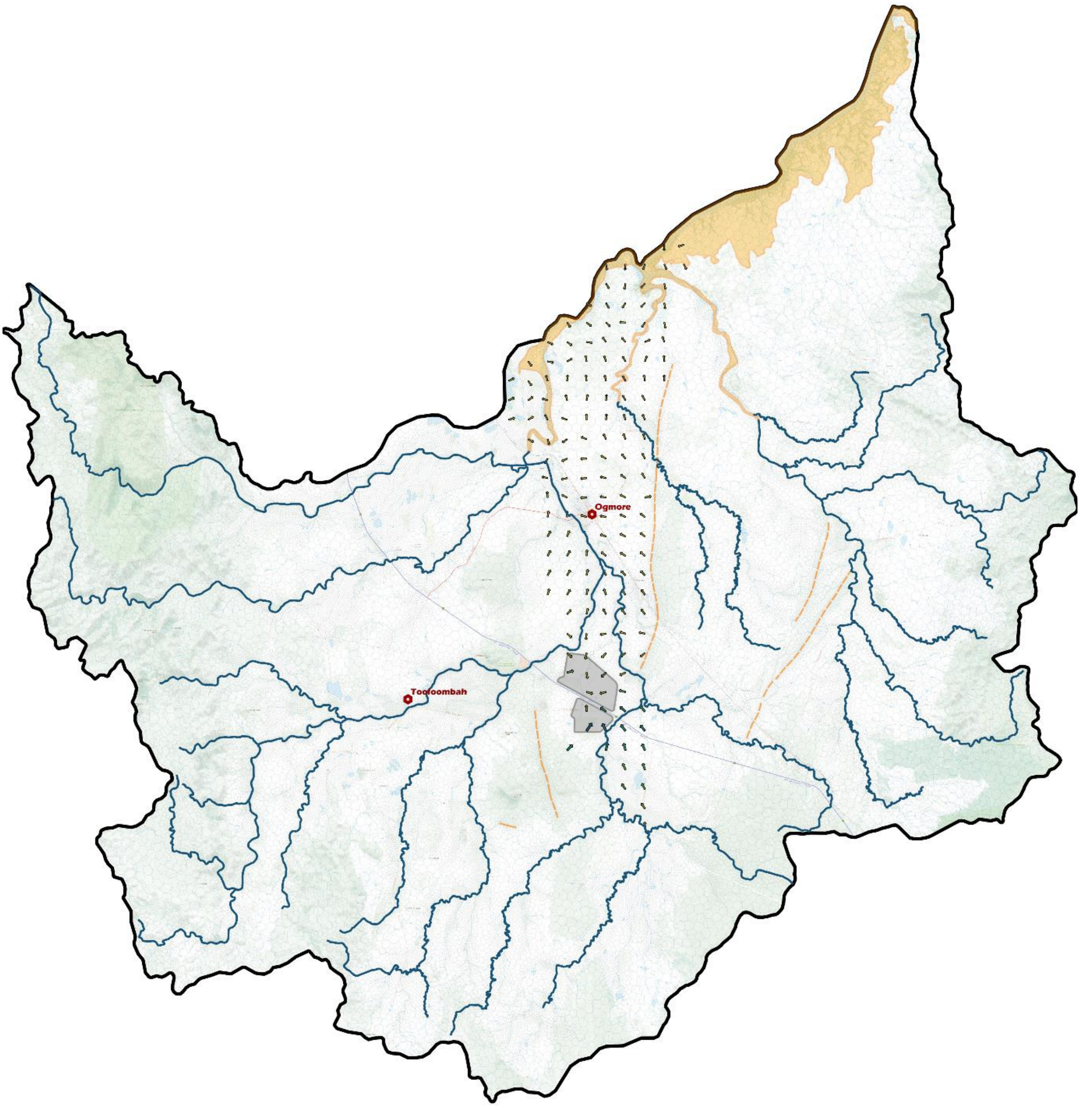


Figure 8-6(e)

Post-Mining [+100 Years (Approximate)] Head Gradients (Flow Direction) in Styx Coal Measures (Layer 8)

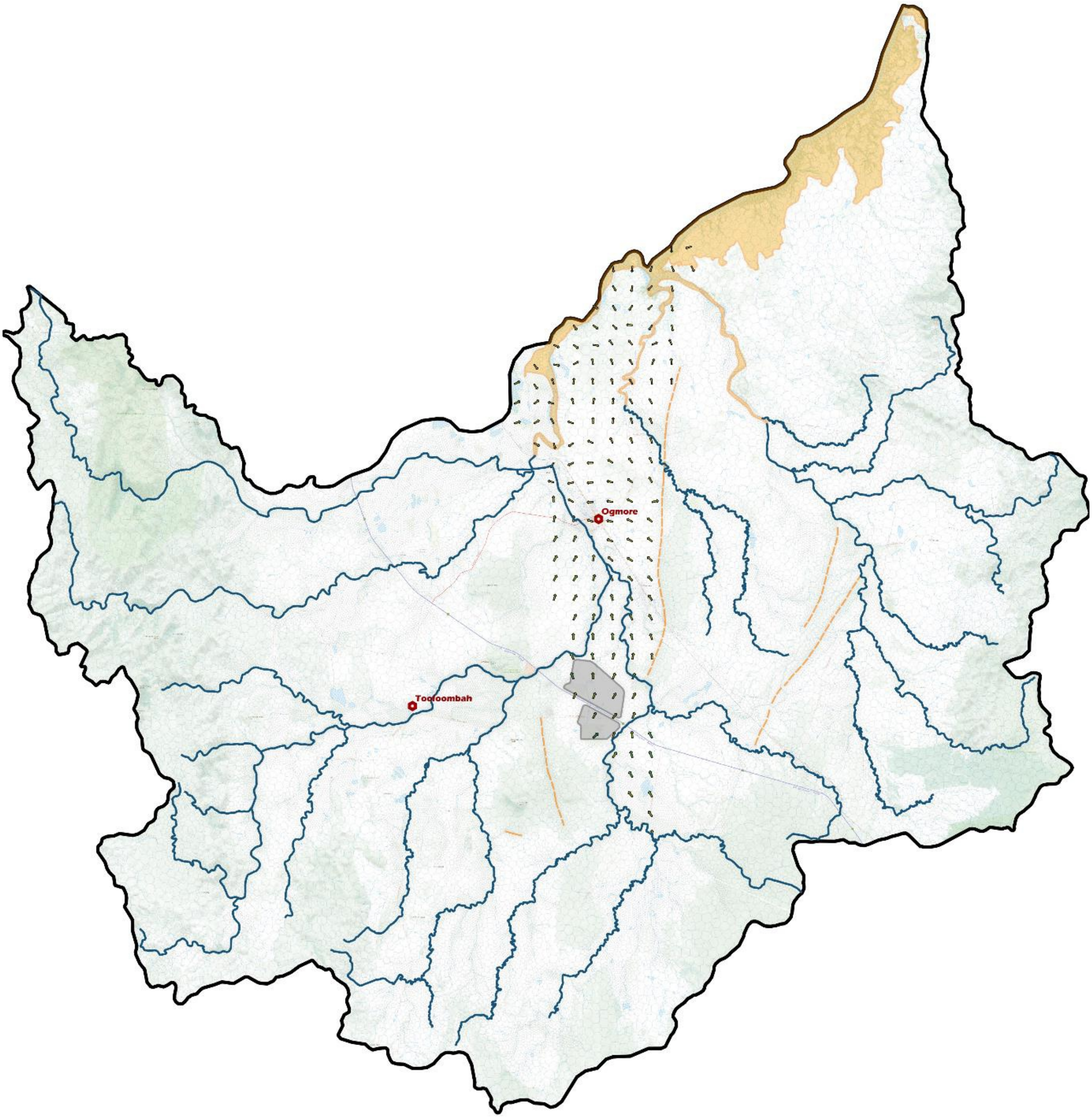
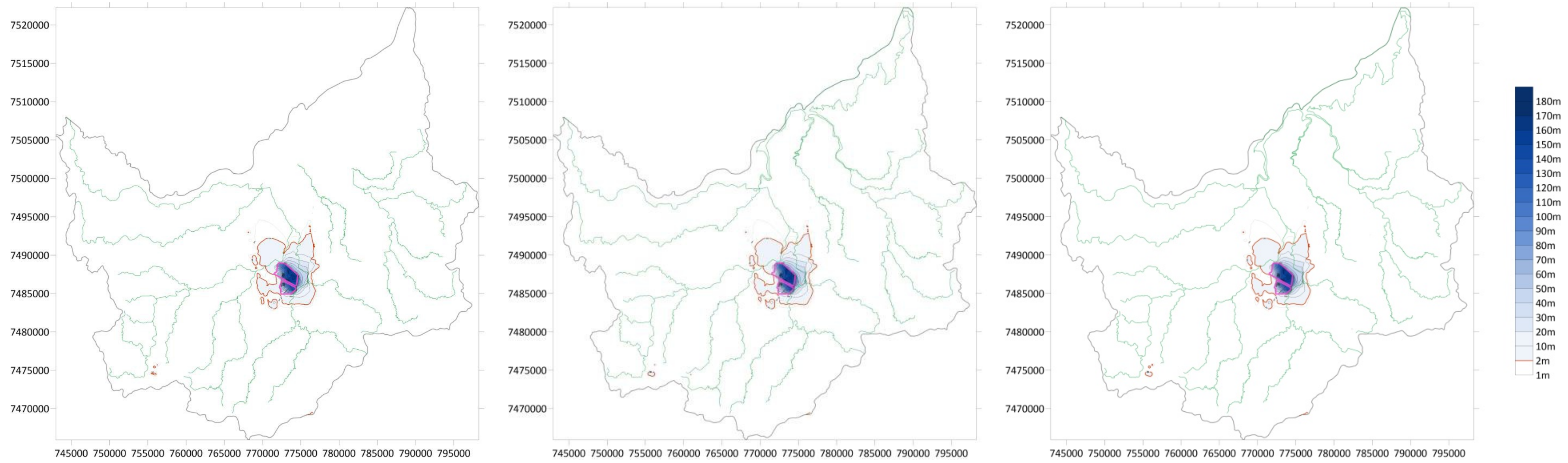


Figure 8-6(f)

Post-Mining [+500 Years (Approximate)] Head Gradients (Flow Direction) in Styx Coal Measures (Layer 8)



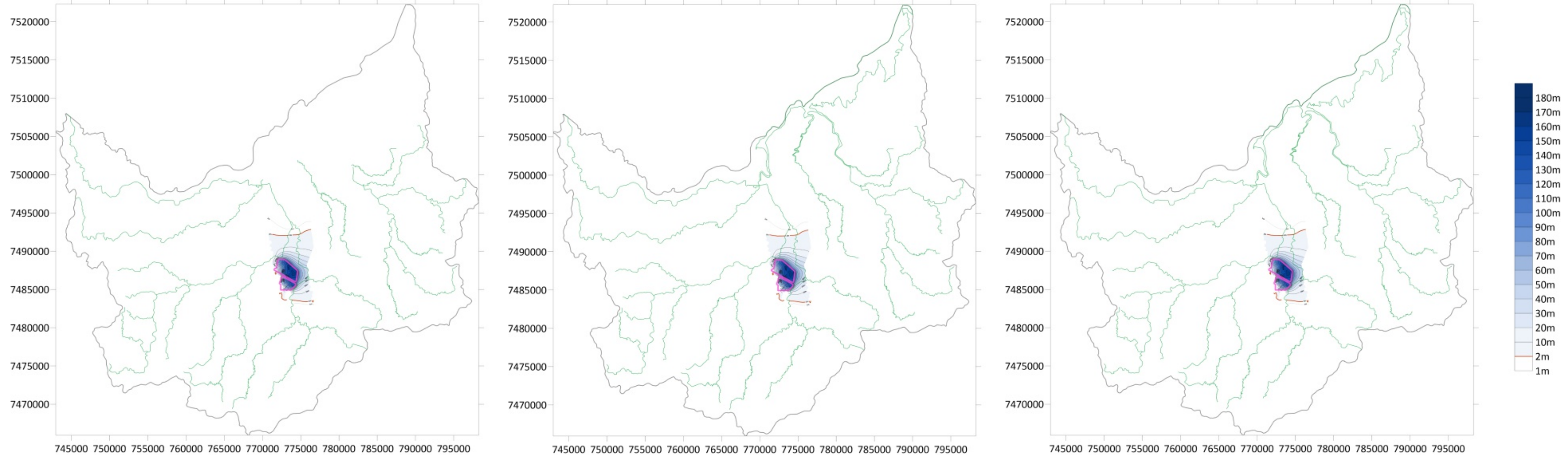
LF3 Case (3.5 mAHD)

Low Case (2 mAHD)

High Case (4.5 mAHD)

Figure 8-7(a)

Tidal Boundary Condition Range Sensitivity Analysis (Layer 2) – Maximum Predicted Drawdown



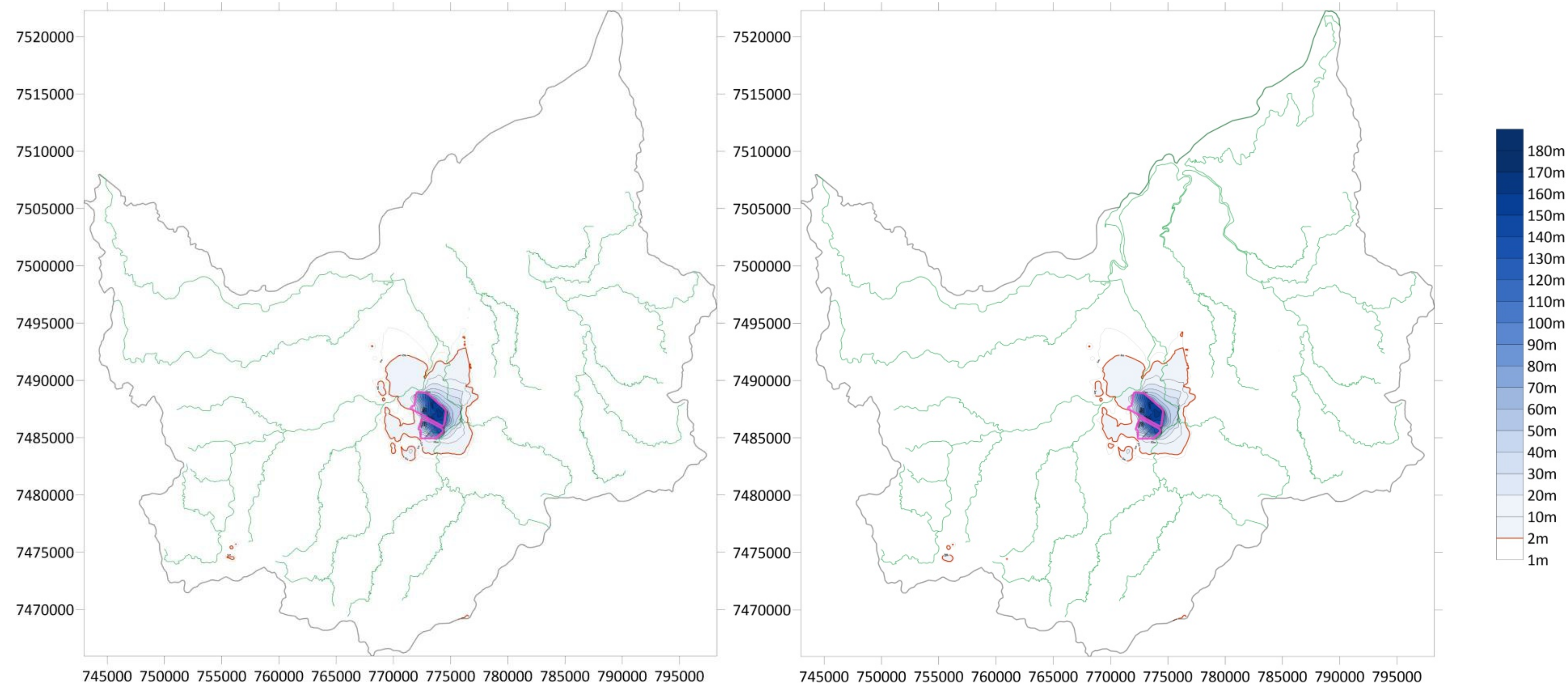
LF3 Case (3.5 mAHD)

Low Case (2 mAHD)

High Case (4.5 mAHD)

Figure 8-7(b)

Tidal Boundary Condition Range Sensitivity Analysis (Layer 8) – Maximum Predicted Drawdown



LF3 Case

Enhanced Case

Figure 8-8(a)

Geological Structure (Fault) Zone Enhanced Hydraulic Conductivity Sensitivity Analysis (Layer 2) – Maximum Predicted Drawdown

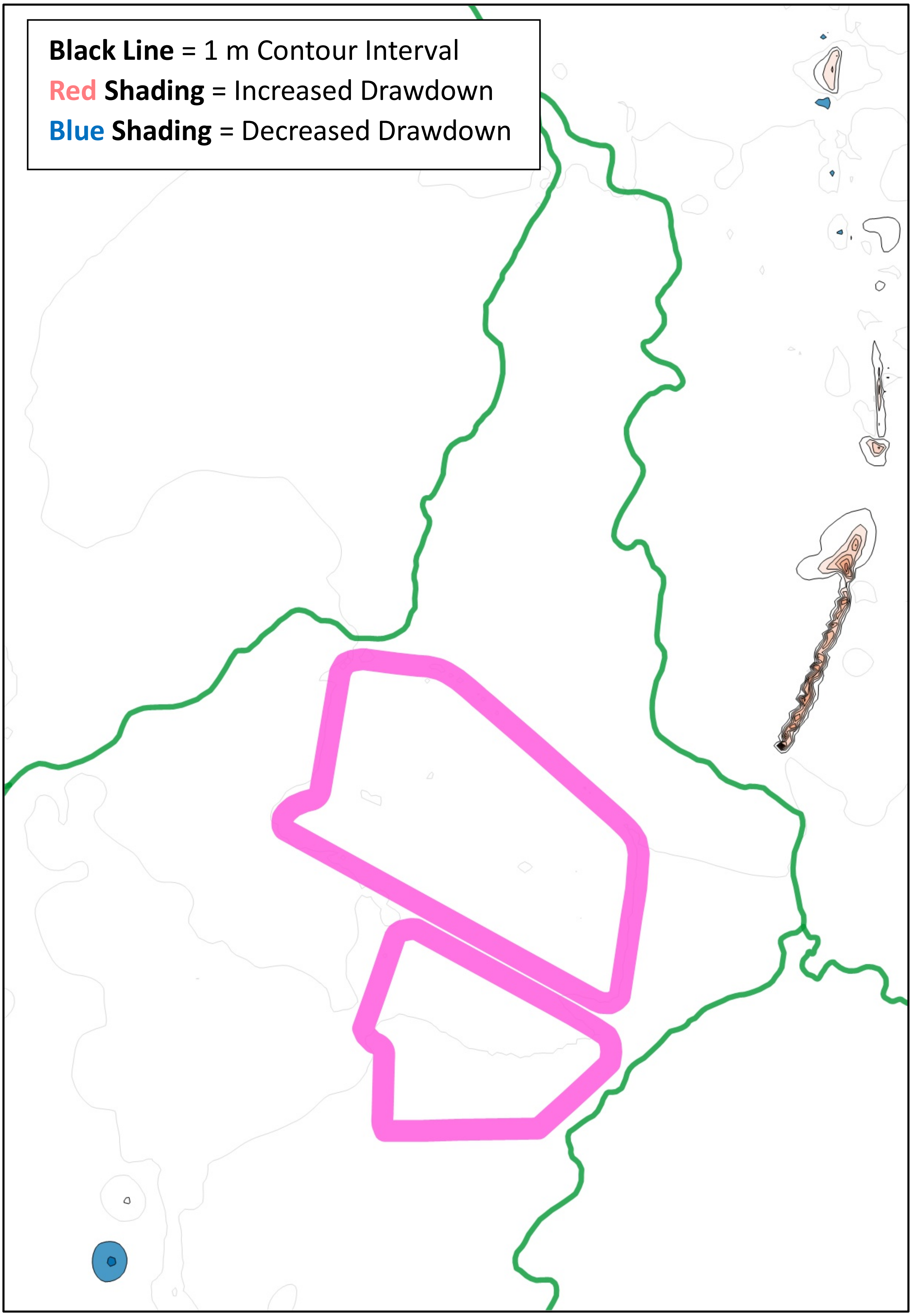
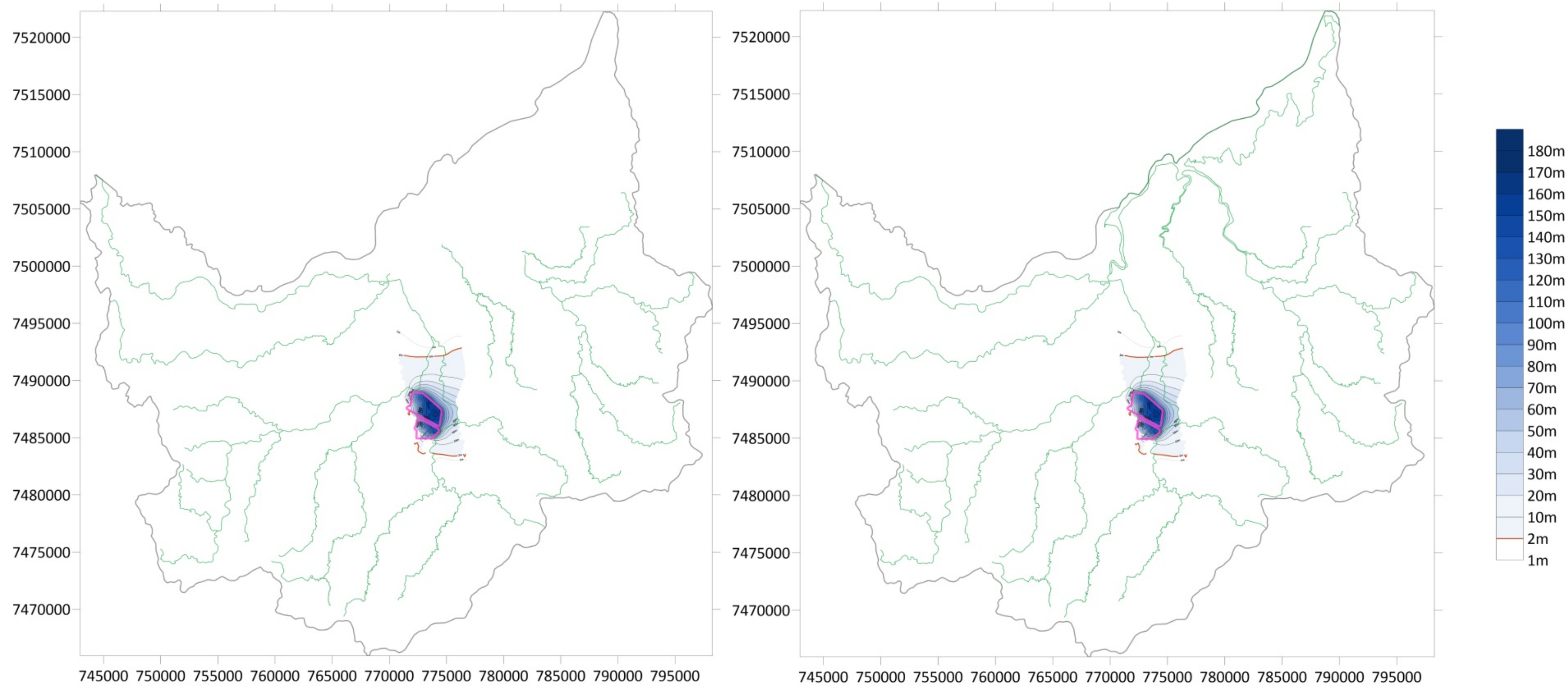


Figure 8-8(b)

Geological Structure (Fault) Zone Enhanced Hydraulic Conductivity Sensitivity Analysis (Layer 2) - Localised Differences [LF3 Case Minus Enhanced Case]

HYDRO ALGORITHMICS

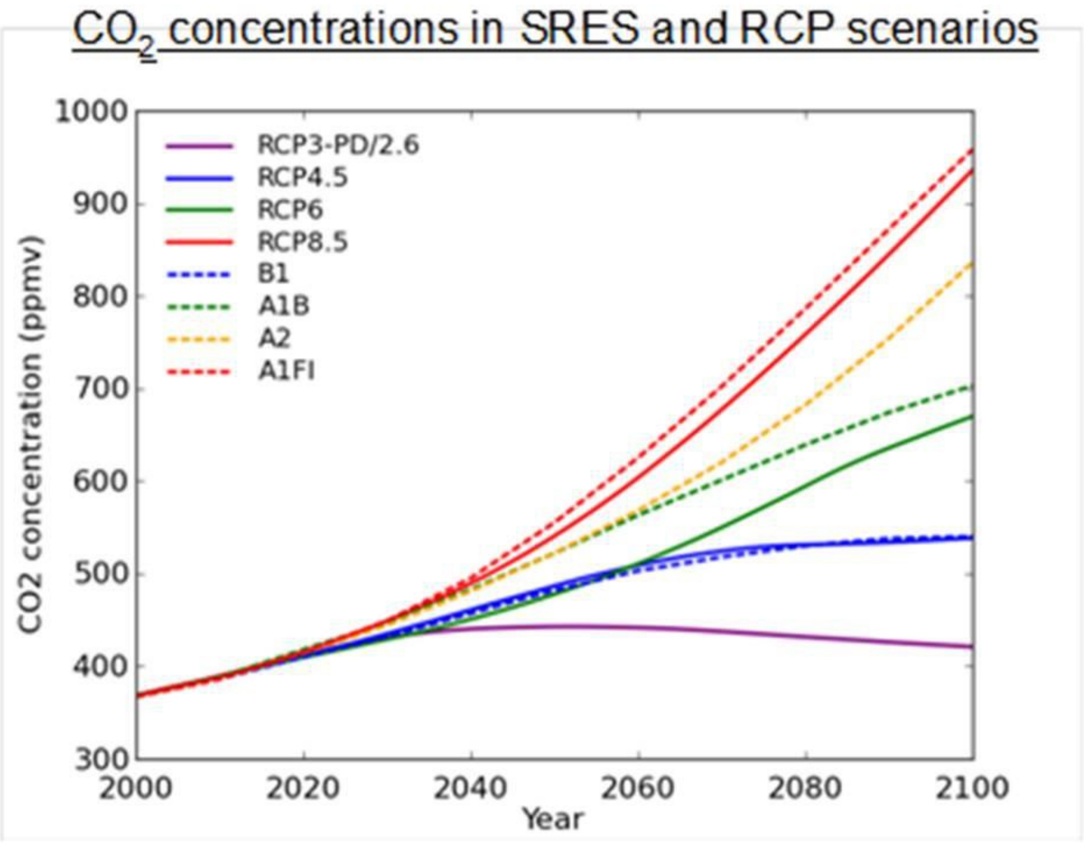


LF3 Case

Enhanced Case

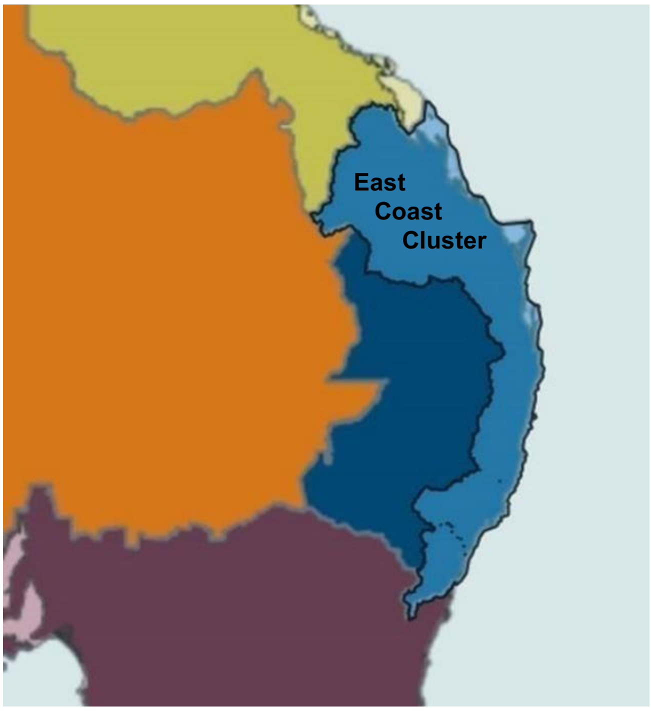
Figure 8-8(c)

Geological Structure (Fault) Zone Enhanced Hydraulic Conductivity Sensitivity Analysis (Layer 8) – Maximum Predicted Drawdown



[a] Climate Model Scenario Comparisons [SRES and RCP]

[*Source: After https://www.climatechangeinaustralia.gov.au/en*]



[b] East Coast Cluster

[*Source: After https://www.climatechangeinaustralia.gov.au/en*]

Figure 8-9

Climate Change in Australia Predictions

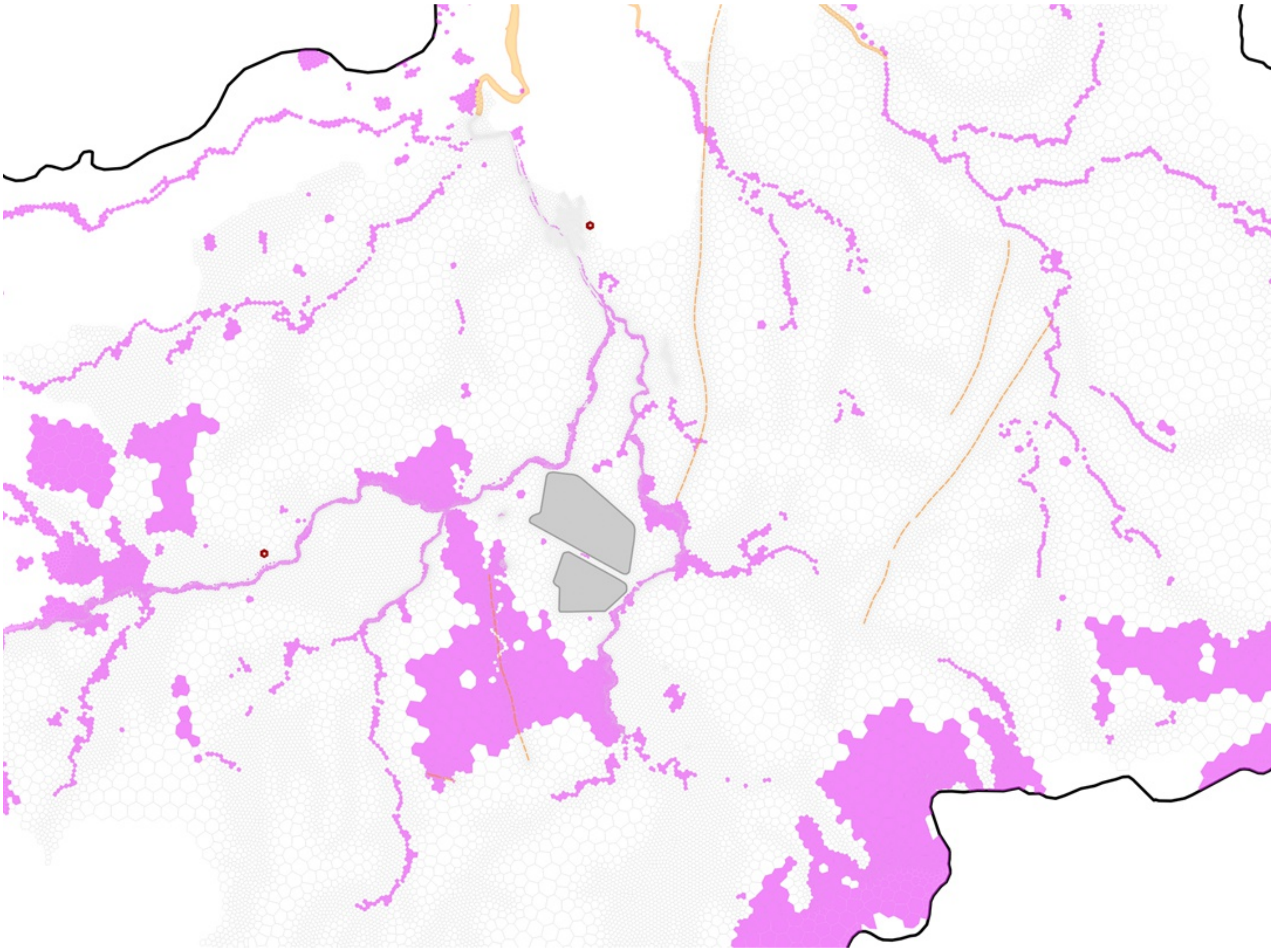


Figure 8-10

Model Sensitivity Run – Application of ET Extinction Depth to 8 m (Pink Cells)

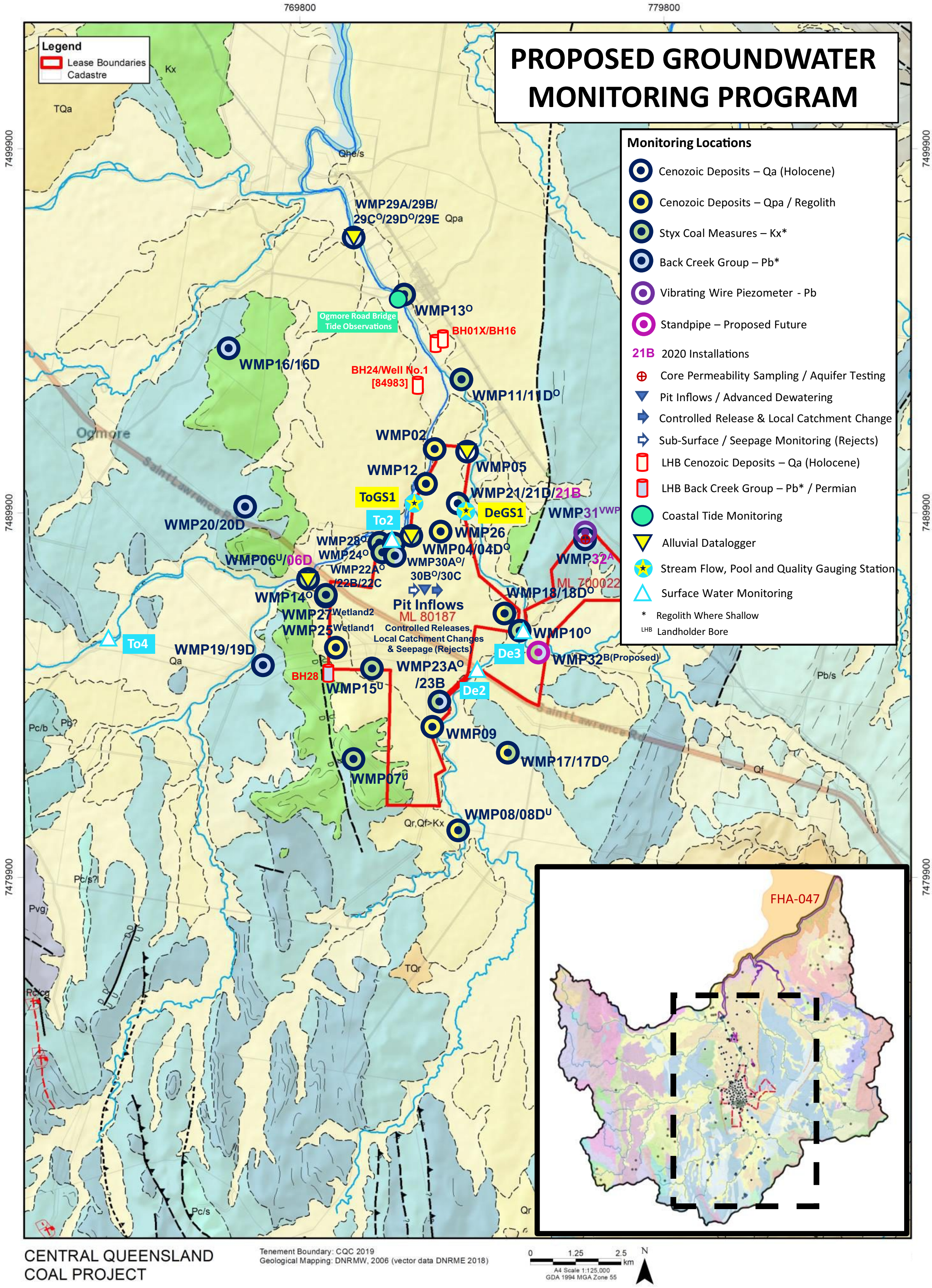


Figure 10-1

Proposed Groundwater Monitoring Program

HYDRO ALGORITHMICS

ATTACHMENT 4
GROUNDWATER MONITORING LOCATIONS, INSTALLATION DETAILS, LANDHOLDER BORE AND CENSUS DETAILS, AND NORTH-EAST / EAST DRILL HOLE GEOLOGICAL AND GEOPHYSICAL LOGS
(CQCPL, 2019)

Table A4-1
Groundwater Monitoring Locations and Installation Details

Bore Number / Reference		Easting	Northing	Elevation (mAHD)	Date Drilled	Total Depth (mbgl)	Screen Interval (mbgl)	Indicative Stratigraphic Interval(s)
WMP02	CMB16	773497	7491734	25.0	1-Oct-17	18.4	12-18	Qa / **Qpa / Regolith**
WMP04	CMB13	772865	7489358	28.3	11-Oct-17	18.4	12-18	Qa / **Qpa / Regolith**
WMP04D	CMB14	772859	7489351	28.3	29-Sep-17	36.5	18.5-36.3	Qpa / **Regolith / Kx[o]**
WMP05	CMB01	774507	7491639	17.2	30-Sep-17	12.4	9-12	**Qa**
WMP06	-	770020	7488120	34.0	3-Nov-17	18.4	12-18	**Regolith / Kx[u]**
WMP07	CMB08	771264	7483151	131.0	16-Oct-17	60.0	48-60	**Kx [u]**
WMP08	RMB06	774134	7481232	43.5	2-Nov-17	16.0	10-16	Qa / **Qpa / Regolith**
WMP08D	RMB07	774134	7481232	43.5	2-Nov-17	36.0	24-36	**Kx [u]**
WMP09	CMB07	773459	7484062	37.6	14-Oct-17	15.4	7.1-15	Qa / **Qpa / Regolith**
WMP10	CMB06	775878	7486688	29.3	13-Oct-17	18.4	12-18	**Kx[o]**
WMP11	-	774194	7493610	18.8	18-Mar-18	24.0	18-24	**Kx[o]**
WMP11D	RMB03	774201	7493623	18.8	17-Mar-18	36.0	30-36	**Kx[o]**
WMP12	CMB15	773266	7490731	26.4	6-Nov-17	18.0	11-17	Qa / **Qpa / Regolith**
WMP13	RMB01	772604	7495931	18.4	12-Jan-18	19.7	12.7-19.7	Qpa / Regolith / **Kx [o]**
WMP14	CMB11	770477	7487637	32.9	19-Mar-18	18.0	9-18	**Regolith / Kx [o]**
WMP15	CMB09	771774	7485564	43.3	20-Mar-18	21.0	9.3-21.3	**Regolith / Kx [u] / Pb**
WMP16	RMB10	767930	7494387	41.9	20-Oct-18	31.5	25.5-31.5	**Pb**
WMP16D	RMB11	767923	7494380	41.8	21-Oct-18	42.0	35.7-41.7	**Pb**
WMP17	RMB04	775465	7483308	42.8	3-Oct-18	12.0	9-12	Qa / **Qpa / Regolith**
WMP17D	RMB05	775470	7483286	42.8	2-Oct-18	24.0	21-24	**Kx[o]**
WMP18	CMB04	775366	7487144	30.5	13-Sep-18	12.2	9.2-12.2	Qa / **Qpa / Regolith**
WMP18D	CMB05	775358	7487152	30.6	12-Sep-18	23.5	18.5-23.5	**Kx [o]**
WMP19	RMB08	768808	7485676	41.0	6-Sep-18	16.1	13.1-16.1	Regolith / **Pb**
WMP19D	RMB09	768801	7485692	41.0	7-Sep-18	28.0	24.9-27.9	**Pb**
WMP20	RMB12	768251	7490084	43.0	20-Oct-18	20.5	14.5-20.5	Regolith / **Pb**
WMP20D	RMB13	768246	7490082	43.0	20-Oct-18	30.0	24-30	**Pb**
WMP21	CMB02	774294	7490072	23.8	10-Sep-18	9.9	6.9-9.9	**Qa**
WMP21D	CMB03	774243	7490004	26.0	10-Sep-18	22.0	14-20	**Regolith / Kx [o]**
WMP22A	CMB17	772008	7488891	29.7	19-Oct-18	30.0	27-30	**Kx [o]**
WMP22B	CMB18	772011	7488896	29.7	19-Oct-18	56.0	50-56	**Kx [Red Seam]**
WMP22C	CMB19	772012	7488900	29.8	19-Oct-18	206.0	200-206	**Pb**
WMP23A	-	773651	7474701	36.4	6-Oct-18	56.5	48.5-54.5	**Kx [i] [Above Blue]**

Table A4-1 (Continued)
Groundwater Monitoring Locations and Installation Details

Bore Number / Reference		Easting	Northing	Elevation (mAHD)*	Date Drilled	Total Depth (mbgl)	Screen Interval (mbgl)	Indicative Stratigraphic Interval(s)
WMP23B	-	773638	7484709	36.4	6-Oct-18	194.0	187-193	Pb / **Pc$_s$**
WMP24	CMB22	771965	7489093	19.4	11-Sep-18	26.4	23.4-26.4	**Kx [o]**
WMP25 [Wetland 1]	CMB10	770812	7486227	44.2	8-Sep-18	13.2	10.1-13.1	Qa / **Qpa / Regolith**
WMP26	CMB23	773655	7489372	27.6	9-Sep-18	20.5	11.5-20.5	Qa / **Qpa / Regolith**
WMP27 [Wetland 2]	CMB24	770606	7487750	33.0	8-Sep-18	20.5	14.5-20.5	Regolith / **Kx [o]**
WMP28	CMB25	772192	7489099	21.9	11-Sep-18	12.0	8.9-11.9	Regolith / **Kx [o]**
WMP29A	RMB14	771298	7497385	12.0	28-Oct-18	12.5	6.5-12.5	**Qhe** / Qa
WMP29B	RMB15	771301	7497385	12.0	28-Oct-18	20.0	16-20	Qa / **Qpa / Regolith**
WMP29C	RMB16	771318	7497394	12.0	27-Oct-18	58.0	52-58	**Kx [o]**
WMP29D	RMB17	771317	7497387	12.0	1-Nov-18	121.0	115-121	**Kx [i] [Above Blue]**
WMP29E	RMB18	771312	7497397	12.0	31-Oct-18	228.5	222.5-228.5	**Pb**
WMP30A	-	772028	7488896	29.8	19-Oct-18	30.0	27-30	**Kx [o]**
WMP30B	-	772028	7488900	29.8	19-Oct-18	56.0	50-56	**Kx [Red Seam]**
WMP30C	-	772029	7488905	29.7	19-Oct-18	206.0	200-206	**Pb**
BH1	Wetland 1	770792	7486241	44.2	28-Aug-18	4.2	Backfilled	Qa / **Qpa / Regolith**
BH2	Wetland 1	770858	7486217	44.2	28-Aug-18	4.0	Backfilled	Qa / **Qpa / Regolith**
BH3	Wetland 1	770796	7486240	44.2	28-Aug-18	14.5	Backfilled	**Regolith / Kx [u]**
BH4	Wetland 2	770643	7487718	33.0	30-Aug-18	4.2	Backfilled	Qa / **Qpa / Regolith**
BH5	Wetland 2	770627	7487717	33.0	30-Aug-18	15.0	Backfilled	Qa / **Qpa / Regolith**
BH6	Alluvial Thicket	772191	7489107	21.9	29-Aug-18	9.9	Backfilled	**Qa**
STX00038	-	772160	7486136	70.7	9-Nov-08	75.1	Exploration	**Kx [u]**
STX00077	-	774032	7486352	32.9	< 2011	148.1	Exploration	**Kx [u]**
STX00081	-	772636	7485920	33.4	12-Feb-11	107.6	Exploration	**Kx [u]**
STX00090	-	774287	7485398	34.9	17-Feb-11	77.8	Exploration	**Kx [u]**
STX00091	-	773562	7484585	36.5	20-Feb-11	75.2	Exploration	**Kx [u]**
STX00093	-	774042	7485069	35.8	26-Feb-11	75	Exploration	**Kx [u]**
STX00095	-	774549	7486255	33.0	15-Apr-11	75.8	Exploration	**Kx [u]**
STX00097	-	773243	7486750	31.8	22-Apr-11	74.9	Exploration	**Kx [u]**
STX00100	-	772046	7486619	38.4	19-Feb-11	77.8	Exploration	**Kx [u]**
STX00103	-	773375	7485206	35.2	21-Oct-14	82.0	Exploration	**Kx [u]**
STX00104	-	773234	7485348	34.8	5-Nov-14	81.5	Exploration	**Kx [u]**
STX00105	-	773849	7487375	30.9	11-Jun-11	74.6	Exploration	**Kx [u]**

Table A4-1 (Continued)
Groundwater Monitoring Locations and Installation Details

Bore Number / Reference		Easting	Northing	Elevation (mAHD)*	Date Drilled	Total Depth (mbgl)	Screen Interval (mbgl)	Indicative Stratigraphic Interval(s)
STX00109	-	773682	7489368	27.2	12-Jul-11	74.6	Exploration	**Kx [u]**
STX00112	-	772235	7485856	40.5	5-Apr-11	95	Exploration	**Kx [u]**
STX00113	-	773634	7486170	32.9	17-Apr-11	110	Exploration	**Kx [u]**
STX00114	-	772965	7486034	33.2	19-Apr-11	74.8	Exploration	**Kx [u]**
STX0126B	-	771954	7487122	37.2	11-May-11	74.6	Exploration	**Kx [u]**
STX00127	-	771436	7487316	37.2	13-May-11	81	Exploration	**Kx [u]**
STX00130	-	772301	7487757	32.3	19-May-11	74.6	Exploration	**Kx [u]**
STX0135C	-	773195	7488193	28.1	3-Jul-11	74.6	Exploration	**Kx [u]**
STX0136C	-	773325	7488695	28.1	11-Jul-11	74.6	Exploration	**Kx [u]**
STX00137	-	773894	7489843	26.9	9-Jul-11	149.7	Exploration	**Kx [u]**
STX00170	-	773169	7485265	34.9	23-Nov-14	66.0	Exploration	**Kx [u]**
STX00204	-	773375	7485489	34.7	18-Oct-14	82.0	Exploration	**Kx [u]**
STX00205	-	773158	7485566	34.8	18-Oct-14	86.3	Exploration	**Kx [u]**
WMP10D	-	775878	7486688	29.3	30-Sep-17	226.0	Exploration	**Kx [u]**
STX1200	-	773491	7485495	34.6	5-Sep-17	165.0	Exploration	**Kx [u]**
STX1201C	-	773875	7485675	34.4	9-Sep-17	150.3	Exploration	**Kx [u]**
STX1202C	-	773209	7486006	33.9	21-Sep-17	117.2	Exploration	**Kx [u]**
STX1203C	-	773372	7487252	30.9	25-Sep-17	135.2	Exploration	**Kx [u]**
STX1204	-	773658	7485627	34.3	18-Oct-17	180	Exploration	**Kx [u]**
STX1205	-	772388	7487796	31.6	4/11/2017	123.3	Exploration	**Kx [u]**
STX1204L	-	773664	7485635	35.4	11-Feb-17	136.4	Exploration	**Pb**
STX1205L	-	772372	7487792	32.6	12-Nov-17	97	Exploration	**Kx [u]**
STX1806_2	-	773666	7485634	34.4	22-Mar-18	249	Exploration	**Pb**
STX1807_2	-	772752	7487594	29.5	24-Mar-18	201	Exploration	**Pb**
STX145C	-	772733	7488419	28.9	31-Jul-11	149.6	Exploration	**Kx [u]**
STX096C	-	774243	7486177	33.1	19-Apr-11	74.6	Exploration	**Kx [u]**
STX073C	-	774483	7485965	33.8	28-Nov-10	162.59	Exploration	**Kx [u]**

* Approximated from LiDAR survey or CQCPL exploration records.

Table A4-2
Landholder Bore Locations and Census Details

Bore Number / Other Reference		Easting	Northing	Approx. Elevation (mAHD)*	Date Drilled (or Before)	Total Depth (mbgl)	Screen Interval (mbgl)	Indicative Stratigraphic Interval(s)
BH01	Hill Paddock Bore (161292)	761920	7482423	69	Jul 2015	30.0^	18-30^	**Pc_s**
BH01X	-	773561	7494524	11	-	10.5	-	**Qa**
BH02X	-	769932	7477272	64	-	13.3	-	Qa / **Qpa / Regolith**
BH03X	-	766972	7479111	59	-	-	-	**Qa**
BH04	Soppa (111418)	772246	7496509	10	Apr 2000	10.2	8.8-11.9^	**Qa**
BH04X	-	765542	7482007	56	-	-	-	**Pb**
BH05X	Soppa / Riverside 2 (111417)	770918	7499541	9	Apr 2000	10.6	9-11^	**Qhe** / Qa
BH06	Shannon (97866)	769036	7475802	74	Jun 1998	20.5	16-24.5^	**Pb**
BH06X	Soppa (91567)	770732	7499500	8	Sep 1990	8.9	7-8.8^	**Qhe** / Qa
BH07	FGShannon (97562)	765346	7475831	77	Oct 1997	30.4^	13.7-30.4^	**Pb**
BH08	91715	769614	7482476	141.6	Sep 1994	47.0^	29-38^	**Kx [u]**
BH13	91572	784371	7485419	83	Oct 1992	30.8	18-24.5^	**Pb / Pbm**
BH16	67652	773592	7494520	10	Feb 1990	9.1	6-9.5^	**Qa**
BH17	White House Bore (97829)	762574	7482280	64	Feb 1990	24.5^	15-22^	**Pc_s**
BH18	88891	777605	7476010	73	Aug 1980	14.1	15.8-25^	Qa / **Qpa / Regolith**
BH19	88890	772863	7474143	74	Jul 1980	17.3	16.2-19.2^	Regolith / **Kx [u]**
BH20	57794	773592	7494520	10	Nov 1979	9.8^	6-9^	**Qa**
BH21	Shannon (88144)	769040	7475802	74	Jun 1965	14.4	11.9-13.7^	**Regolith / Pb**
BH22	88145	766718	7481287	57.6	Jun 1965	18.3^	A&D	**Kx [u]**
BH23	88146	765068	7485360	47	Jun 1965	27.4^	15-17^	**Kx [u]**
BH24	Well No.1 (84983)	773072	7493413	12.2	Jan 1960	2.6^	2-2.6^	**Qa**
BH25	Olive AM OLO / (67654)	773963	7506776	5.3	Mar 1990	7^	6-7^	**Qhe /** Qa
BH26	67653	771516	7502680	12.7	Feb 1990	8^	7-8^	**Qa**
BH28	McCartney (97864)	771053	7485988	44	Jun 1998	55^	32-54^	**Pb / Pbm**
BH29	Neerim 1	775322	7477562	57	< 2011	9	-	**Qa**
BH30 / BH33	Neerim 2	774175	7475211	67	< 2011	30	-	Regolith / **Kx [o]**
BH32 / BH34	Neerim 3	774433	7470634	106	< 2011	16.8	-	**Regolith / Pb**
BH35	Neerim 4 (91191)	774560	7470829	102	Dec 1993	11.8	10-19^	**Regolith / Kx [o]**

Table A4-2 (Continued)
Landholder Bore Locations and Census Details

Bore Number / Other Reference		Easting	Northing	Approx. Elevation (mAHD)*	Date Drilled (or Before)	Total Depth (mbgl)	Screen Interval (mbgl)	Indicative Stratigraphic Interval(s)
BH37	Soppa / Riverside 1 (67656)	770505	7499287	12	Mar 1990	6.8	7-10^	**Qhe** / Qa
Well01	-	770773	7499515	9	-	7.6	-	**Qhe** / Qa
67650	-	791793	7492413	96.4	Feb 1990	20.5	16-19^	**Lizzie Creek / Pc$_s$**
67651	P179	791978	7496139	59.2	Feb 1990	40	24-40^	**Lizzie Creek / Pc$_s$**
88889	ABD Bore 1 OLO	778302	7476653	79.7	Nov 1965	13.7	-	**Ta**
88890	New Bore 2 OLO	772928	7474249	70.8	Jul 1980	19.2	16.2-19.2^	**Kx [u]**
88891	Replaced ABD Bore 1	778009	7476490	76.6	Aug 1980	25.3	15.8-25^	**Ta**
88892	Bore 4	773994	7470308	120.3	-	25	-	**Pb / Pbm**
91455	Shannon No.1 OLO	753531	7487736	195.6	Jun 1965	29	24.2-29^	**Lizzie Creek / Pc$_s$**
91456	Shannon No.2 OLO	753686	7492883	125.8	Jun 1965	16.8	13.7-15.3^	**Lizzie Creek / Pc$_s$**
91457	Shannon No.3 OLO	757948	7496213	41.3	Jun 1965	20.4	16.8-20.4^	**Lizzie Creek / Pc$_s$**
91746	New Hope 9013	767912	7499540	17.6	Nov 1993	17	A&D	**Qa**
91748	New Hope 9014	768962	7499842	17	Nov 1993	96.5	A&D	**Kx [o]**
91749	New Hope 9015	769260	7499823	16.6	Nov 1993	83.5	A&D	**Kx [o]**
91750	New Hope 9016	769594	7499914	15.9	Nov 1993	92.8	A&D	**Kx [o]**
91751	New Hope 9017	768873	7500948	15.5	Nov 1993	83.5	A&D	**Kx [o]**
91752	New Hope 9018	769229	7501075	14.7	Nov 1993	59.5	A&D	**Kx [o]**
91753	New Hope 9019	769144	7503267	12.5	Nov 1993	125.5	A&D	**Kx [o]**
91884	Galea OLO	786109	7507969	22.1	Mar 1990	24	18-24^	**Volcanic Granite**
97381	Galea	783381	7499036	23.8	Oct 1994	19	13-19^	**Lizzie Creek / Pc$_s$**
97641	P97 – Galea S	782947	7504271	20	Jan 1993	12.2	-	**-**
97654	Montrose Grazing Co	756868	7488875	76.7	Nov 1997	24	15-24^	**Lizzie Creek / Pc$_s$**
97825	White – Scrub Dam Bore	760346	7477026	310.1	Oct 1997	24	9-24^	**Volcanic Basement**
97826	White – Old Mill Bore	761097	7478342	129.6	Oct 1997	18	9-18^	**Volcanic Basement**

Table A4-2 (Continued)
Landholder Bore Locations and Census Details

Bore Number / Other Reference		Easting	Northing	Approx. Elevation (mAHD)*	Date Drilled (or Before)	Total Depth (mbgl)	Screen Interval (mbgl)	Indicative Stratigraphic Interval(s)
97827	White – Bullock Pad #2	756185	7474962	161.9	Jan 1994	30	18-30^	**Lizzie Creek / Pc_s**
97828	White – Langdale Bore	761427	7473161	164.1	Feb 1990	26	13-26^	**Volcanic Basement**
97830	White	756763	7474932	146.1	Apr 1998	19	10-18.5^	**Lizzie Creek / Pc_s**
111311	-	786515	7487853	50.1	-	12.5	N/A	**Pb / Pbm**
111312	Hals Bore	790318	7485613	73.2	Jan 1967	19.2	N/A	**Pb / Pbm**
111428	Bowman	786932	7485677	60.6	Mar 2000	17.1	9.1-17.1&	**Lizzie Creek / Pc_s**
111429	Bowman	790416	7485356	77.2	Mar 2000	27.4	15.2-27.4^	**Lizzie Creek / Pc_s**
111480	Beresford	788665	7513347	14.6	Apr 2000	21.3	12.2-21.3^	**Lizzie Creek / Pc_s**
111543	Bowman	791178	7487803	92.1	Aug 2001	30.5	18.3-30.5^	**Lizzie Creek / Pc_s**
111559	Vella	788152	7510912	14.6	Oct 2001	21.3	15.2-21.3^	**Lizzie Creek / Pc_s**
111560	Vella	789766	7510724	27.7	Oct 2001	21.3	18.3-30.5^	**Lizzie Creek / Pc_s**
111565	Vella	790450	7514756	53.6	Oct 2001	18.3	9.1-18.3^	**Lizzie Creek / Pc_s**
111566	Vella	787920	7512001	13.4	Oct 2001	6.1	3.1-6.1^	**Qa**
111568	Ferris	787721	7482638	83.9	Oct 2001	24.4	13.7-24.4^	**Lizzie Creek / Pc_s**
111593	Galea	784506	7501825	35.1	Oct 2001	18.3	9.1-18.3^	**Lizzie Creek / Pc_s**
122160	Alice Springs Pastoral	790682	7496434	50	Oct 2004	30	19.8-29.8^	**Lizzie Creek / Pc_s**
122161	Alice Springs Pastoral	790389	7499115	47.7	Oct 2004	30	A&D	**Lizzie Creek / Pc_s**
122164	Platanus	790722	7499361	52.6	Oct 2004	48.7	A&D	**Lizzie Creek / Pc_s**
122987	-	789539	7512400	39.3	Oct 2004	36	24-35^	**Lizzie Creek / Pc_s**
122989	-	790079	7510666	34.7	Oct 2004	24	18-23^	**Lizzie Creek / Pc_s**
122994	-	750200	7473725	322.2	Oct 2004	41.0	35-40^	**Volcanic Basement**
136063	-	785665	7501020	42.5	Oct 2004	21	A&D	**Lizzie Creek / Pc_s**
136065	-	788569	7512572	19	Oct 2004	16	A&D	**Lizzie Creek / Pc_s**
136307	-	791426	7482317	129.3	Aug 2003	40	28-40^	**Pb / Pbm**
136562	-	790517	7485598	73.9	Jun 2007	27	21-27^	**Lizzie Creek / Pc_s**
151113	-	778843	7501608	19.9	Sep 2009	42	A&D	**Pb / Pbm**
151938	-	787814	7499184	42.75	Apr 2013	36	A&D	**Lizzie Creek / Pc_s**
151942	-	787292	7498795	39.8	Sep 2013	42	30-41.7^	**Volcanic – Youlambie**
151948	Tanderra Scrub	786879	7509283	22.9	Oct 2013	30	12-30^	**Volcanic**
151949	Wellington Bore	787573	7499235	42.7	Oct 2013	36	16.8-36^	**Volcanic**

Table A4-2 (Continued)
Landholder Bore Locations and Census Details

Bore Number / Other Reference		Easting	Northing	Approx. Elevation (mAHD)*	Date Drilled (or Before)	Total Depth (mbgl)	Screen Interval (mbgl)	Indicative Stratigraphic Interval(s)
161189	-	788325	7507322	57.25	Oct 2014	60	30-60^	**Volcanic**
161224	-	788573	7504696	64.2	Oct 2014	24	6-24^	**Volcanic**
161292	Hill Paddock Bore	761934	7481483	81.5	Jul 2015	30	18-30^	**Lizzie Creek / Pc_s**
161293	White Cow Paddock Bore	769606	7470346	109.1	Jul 2015	35	9-24^	**Pb / Pbm**
161351	-	784959	7507900	21.5	Oct 2015	60	52-60^	**Glenprairie Beds**
161355	-	786189	7507274	28.7	Oct 2015	60	A&D	**Glenprairie Beds**
161437	-	751057	7473300	321	Feb 2016	42	A&D	**Volcanic Basement**
161438	-	750469	7475000	353.8	Feb 2016	42	A&D	**Volcanic Basement**
161478	-	756775	7476452	123.8	Jun 2016	30	14-30^	**Lizzie Creek / Pc_s**
161612	-	788564	7488620	54.8	Apr 2017	19	12-18^	**Pb / Pbm**
161945	-	768322	7473200	98.8	Nov 2018	25	19-25^	**Pb / Pbm**
161946	-	761842	7480427	77.9	Nov 2018	30	A&D	**Lizzie Creek / Pc_s**
187278	New Bore	771631	7498628	16.4	Aug 2019	21	15.5-17.5^	Qa / **Qpa / Regolith**
187293	-	763151	7475329	104.7	Sep 2019	37	A&D	**Pb / Pbm**
187294	-	763153	7475407	102.5	Sep 2019	49.8	A&D	**Pb / Pbm**
187295	-	762750	7472344	101.9	Sep 2019	27	15-27^	**Lizzie Creek / Pc_s**
12700003	-	763032	7479418	67.7	Aug 2009	172	A&D	**Lizzie Creek / Pc_s**

* Approximated from LiDAR survey or available topographic datasets.
^ Source: After Qld Government Groundwater Information Bore Reports.
Light Purple Rows – No Longer Existing (A&D = Abandoned and Destroyed).

Table A4-3
Drilling Details and Geological Logs for the North-East and East Drill Holes

Bore Number / Reference		Easting	Northing	Elevation (mAHD)	Date Drilled	Total Depth (mbgl)	Screen Interval (mbgl)	Indicative Stratigraphic Interval(s)	
WMP31	NE Hole	778070	7489063	47.0	15-Dec-19	200	-	**Pb / Pbm**	
WMP32$^{B\wedge}$	East Hole	776567	7486141	-	-	75	57-75	**Pb / Pbm**	**Kx [o]**
WMP21B^{+}	NNE Hole	774294	7490072	-	-	95	-	**Kx [o]**	

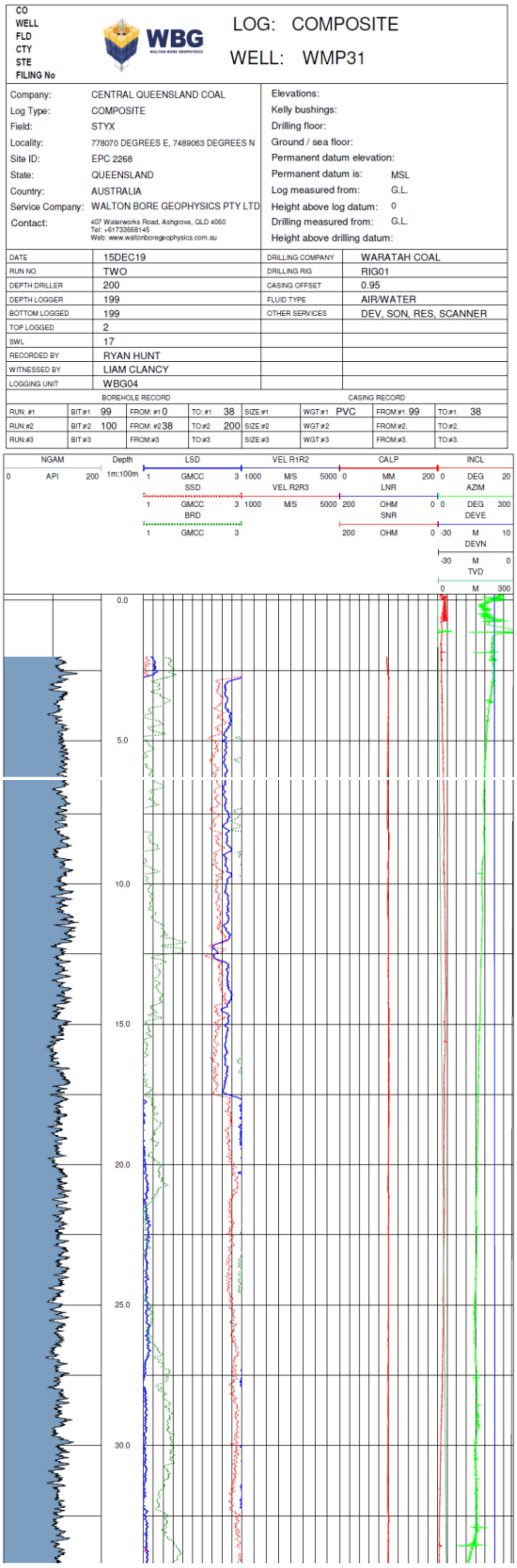
* Approximated from LiDAR survey or available topographic datasets.

^ Proposed at time of reporting.

$^{+}$ Approximate design details only.

WMP31 (SWL @17 mbgl)		
Interval (mbgl)		Lithology
0-12	0-1	**SAND**, fine: mottled brownish-grey, pebbles, extremely weathered, dense, abundant pebbles, cobbles and boulders of sandstone throughout.
	1-3.5	**SANDSTONE**, fine: mottled creamy-grey, minor (1-15%) siltstone bands throughout, distinctly weathered, high strength rock.
	3.5-8	**SANDSTONE**, fine: light creamy-brown, minor (1-15%) siltstone bands throughout, extremely weathered, high strength rock.
	8-12	**SANDSTONE**, fine (50%): light brownish-grey, distinctly weathered, very high strength rock, interbedded with: **SILTSTONE** (50%): dark grey, slightly weathered, high strength rock.
12-199	12-30	**SLATE:** dark blackish-grey, basaltic, conglomeratic throughout, fresh, very high strength rock, minor (1-15%) quartz in veins, accessory olivine coating. Drillers had trouble with this unit. Driller and geo agree that unit contains basaltic boulders, with small amounts of pistachio green very fine grained peridotite crystals covering some of the chips.
	30-47	**SLATE** (80%): dark blackish-grey, rare (<1%) tuffaceous bands, fresh, very high strength rock, minor (1-15%) quartz in veins, interbedded with: **QUARTZITE** (20%): mottled greenish-grey, low grade quartzite.
	47-170	**SLATE** (50%): dark blackish-grey, rare (<1%) tuffaceous bands, fresh, very high strength rock, minor (1-15%) quartz in veins, Faults are common throughout unit, interbedded with: **QUARTZITE** (50%): dark greenish-grey, fresh, very high strength rock.
	170-172	**QUARTZITE**: dark greenish-grey, minor (1-15%) claystone bands throughout, slightly weathered, very high strength rock, minor (1-15%) quartz in veins, clay stone is soft and red.
	172-200	**SLATE** (80%): dark blackish-grey, minor (1-15%) quartzose laminae (2-20mm), fresh, very high strength rock, minor (1-15%) quartz laminae, some of the chips appear to have somewhat schist like qualities as qtz occurs almost like laminae, interbedded with: **QUARTZITE** (20%): dark greenish-grey, fresh, very high strength rock.

Source: CQCPL (2020).



CO
WELL
FLD
CTY
STE
FILING No

WBG
WALTON BORE GEOPHYSICS

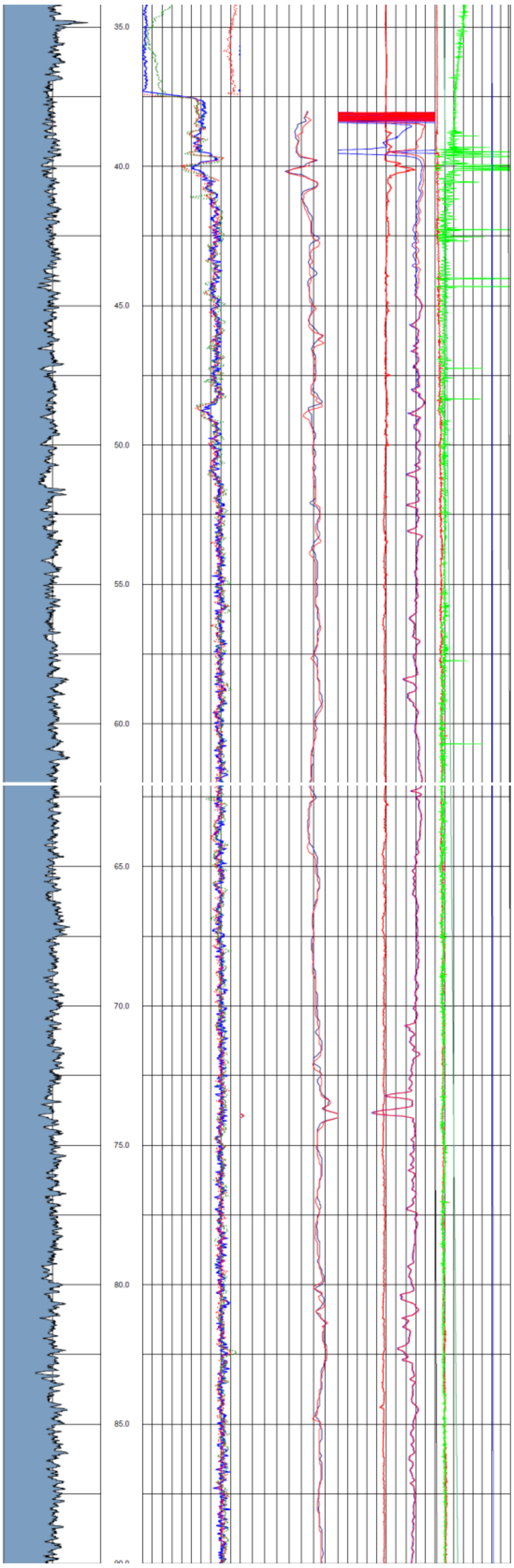
LOG: COMPOSITE

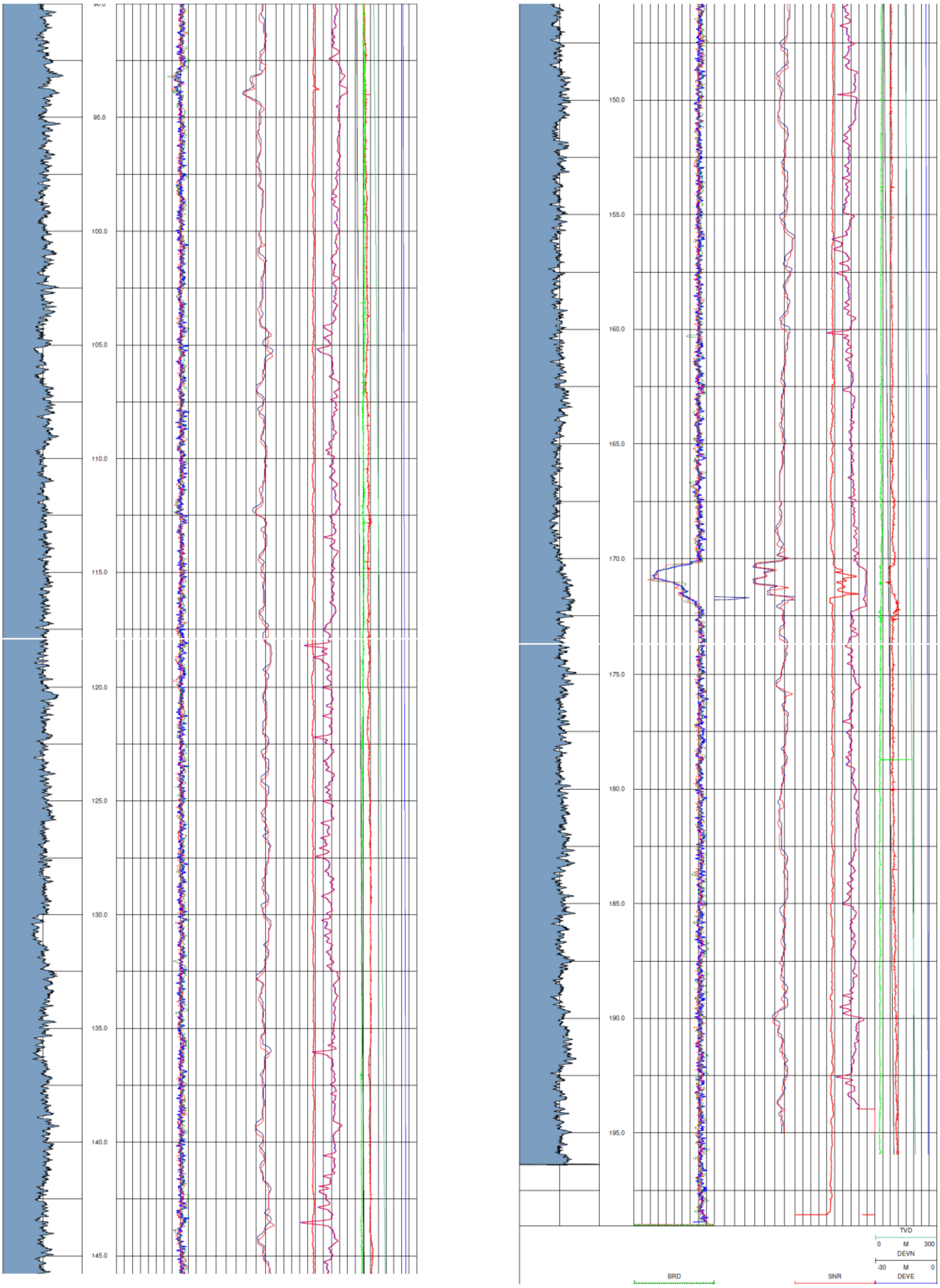
WELL: WMP31

Company:	CENTRAL QUEENSLAND COAL	Elevations:	
Log Type:	COMPOSITE	Kelly bushings:	
Field:	STYX	Drilling floor:	
Locality:	778070 DEGREES E, 7489063 DEGREES N	Ground / sea floor:	
Site ID:	EPC 2268	Permanent datum elevation:	
State:	QUEENSLAND	Permanent datum is:	MSL
Country:	AUSTRALIA	Log measured from:	G.L.
Service Company:	WALTON BORE GEOPHYSICS PTY LTD	Height above log datum:	0
Contact:	407 Waterworks Road, Ashgrove, QLD 4060 Tel: +61733668145 Web: www.waltonboregeophysics.com.au	Drilling measured from:	G.L.
		Height above drilling datum:	

DATE	15DEC19	DRILLING COMPANY	WARATAH COAL
RUN NO.	TWO	DRILLING RIG	RIG01
DEPTH DRILLER	200	CASING OFFSET	0.95
DEPTH LOGGER	199	FLUID TYPE	AIR/WATER
BOTTOM LOGGED	199	OTHER SERVICES	DEV, SON, RES, SCANNER
TOP LOGGED	2		
SWL	17		
RECORDED BY	RYAN HUNT		
WITNESSED BY	LIAM CLANCY		
LOGGING UNIT	WBG04		

BOREHOLE RECORD				CASING RECORD			
RUN: #1	BIT:#1 99	FROM: #1 0	TO: #1 38	SIZE:#1	WGT:#1 PVC	FROM:#1. 99	TO:#1. 38
RUN:#2	BIT:#2 100	FROM: #2 38	TO:#2 200	SIZE:#2	WGT:#2	FROM:#2.	TO:#2.
RUN:#3	BIT:#3	FROM:#3	TO:#3	SIZE:#3	WGT:#3	FROM:#3.	TO:#3.

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105.0
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125.0
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170.0
175.0
180.0
185.0
190.0
195.0
TVD
0 M 300
DEVN
-30 M 0
DEVE
BRD
SNR

ATTACHMENT 5
TRANSIENT ELECTROMAGNETIC SURVEY REPORT
(GROUNDWATER IMAGING, 2019)

CQC Ogmore AgTEM survey for Groundwater Investigation

Tooloombah Creek – Bar-H – Mamelon Crossing

September 2019

For Central Queensland Coal

Attn: Nui Harris, John Bernal

E: j.bernal@waratahcoal.com

M: 0449850642

Stxy River Tidal Limit, Ogmore

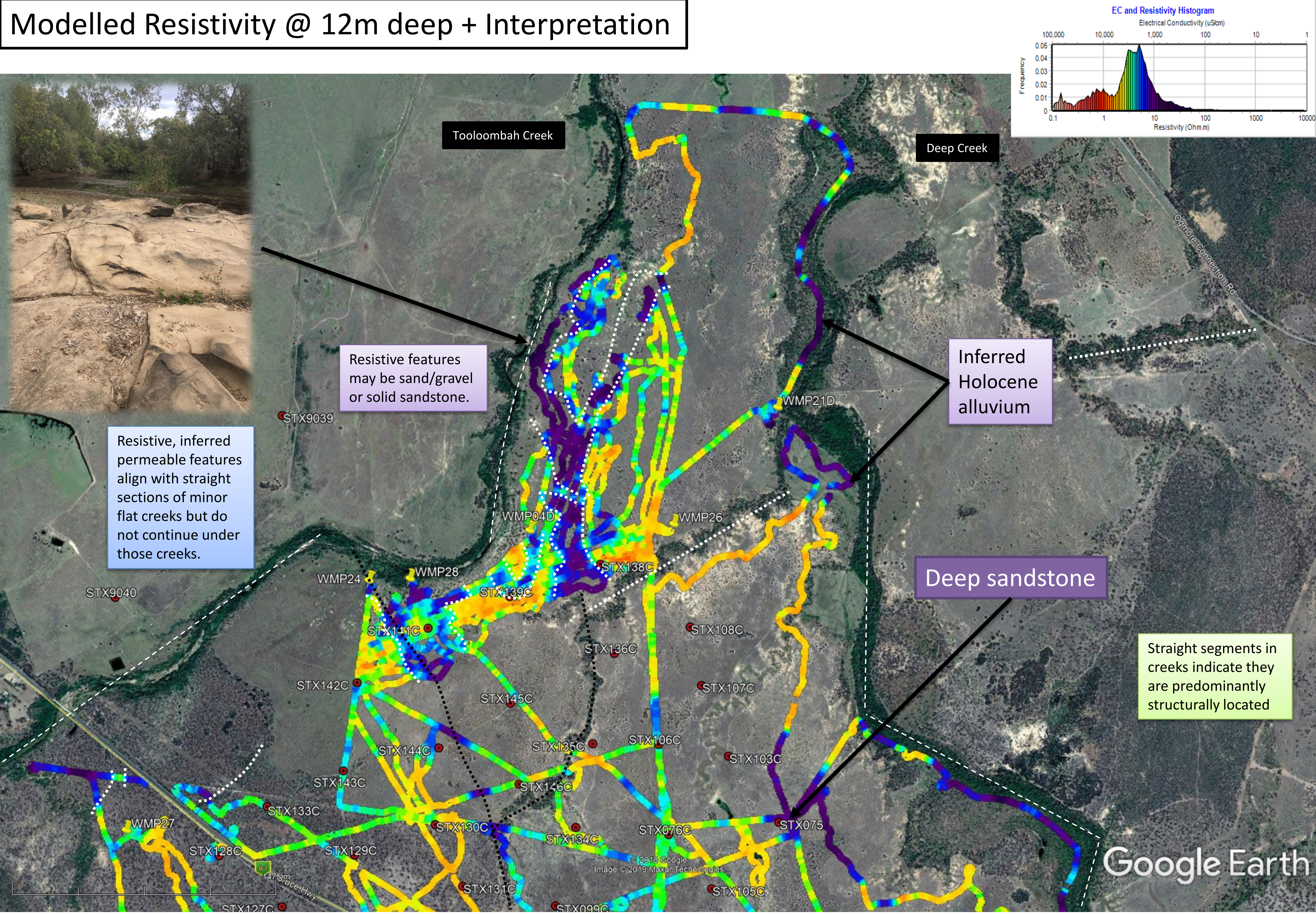
Dr David Allen.

David@GroundwaterImaging.com.au 0418964097

Executive Summary

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

Modelled Resistivity @ 12m deep + Interpretation



Resistive features may be sand/gravel or solid sandstone.

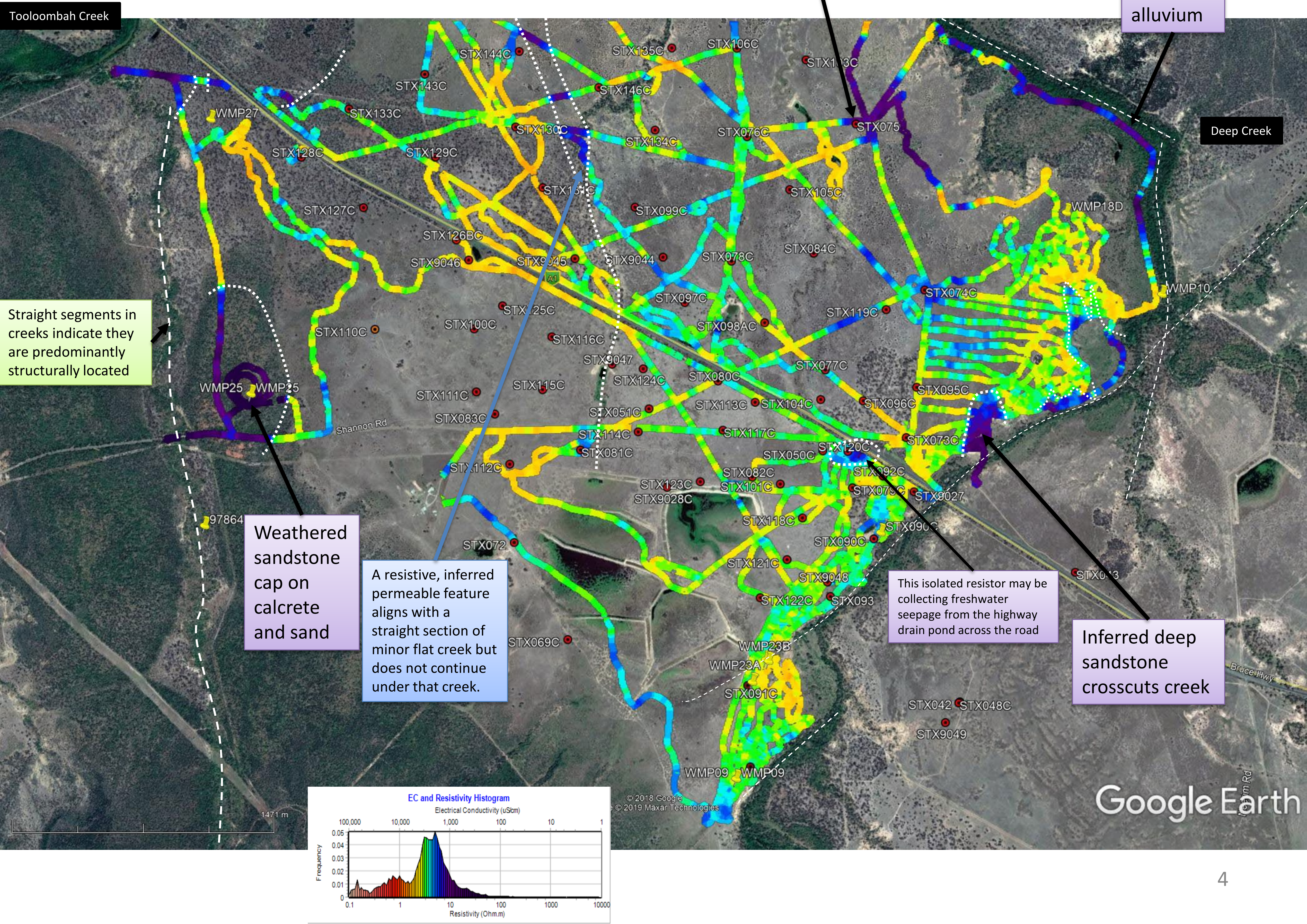
Resistive, inferred permeable features align with straight sections of minor flat creeks but do not continue under those creeks.

Inferred Holocene alluvium

Deep sandstone

Straight segments in creeks indicate they are predominantly structurally located

Modelled Resistivity @ 12m deep + Interpretation



Deep sandstone

Inferred Holocene alluvium

Straight segments in creeks indicate they are predominantly structurally located

Weathered sandstone cap on calcrete and sand

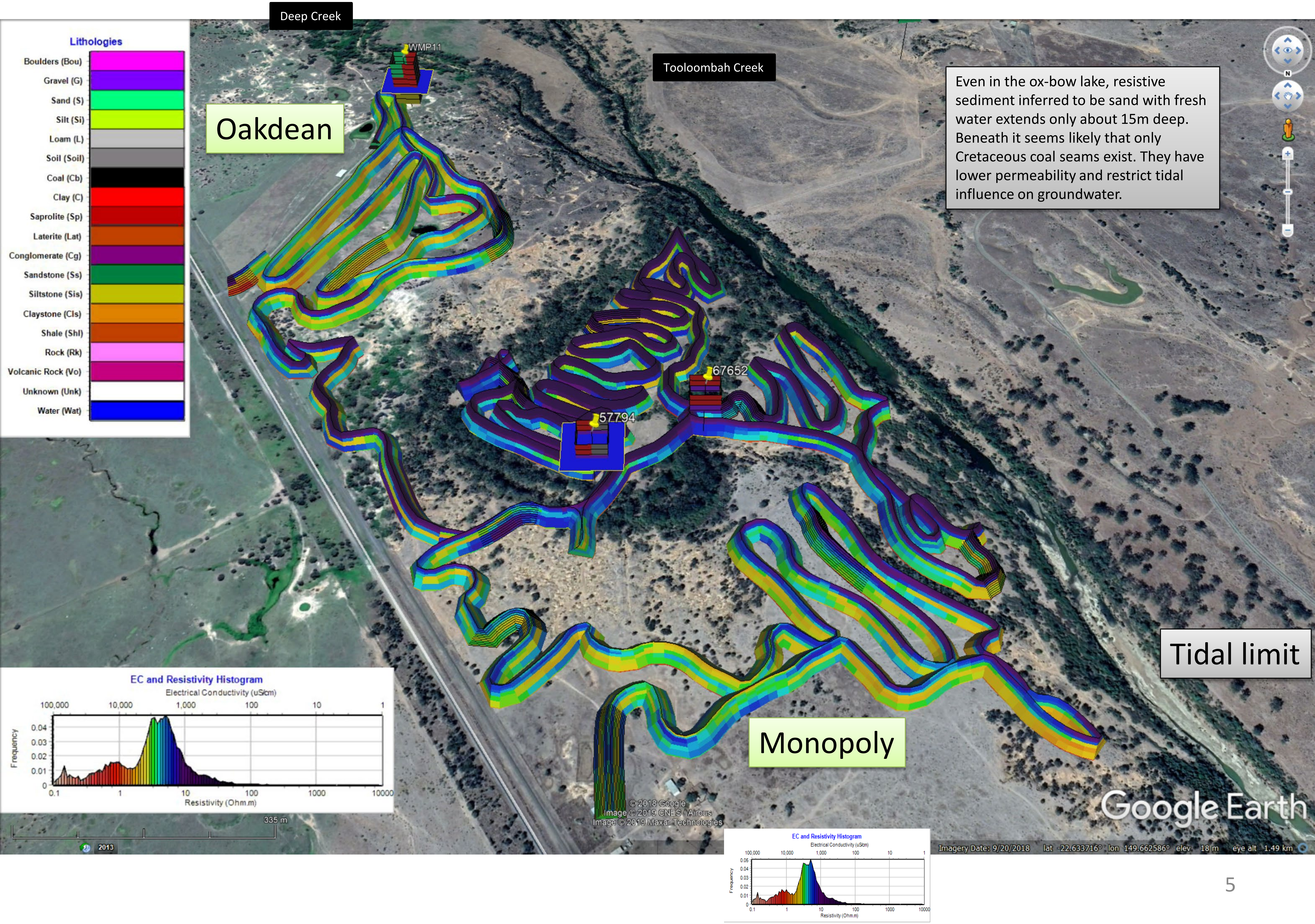
A resistive, inferred permeable feature aligns with a straight section of minor flat creek but does not continue under that creek.

This isolated resistor may be collecting freshwater seepage from the highway drain pond across the road

Inferred deep sandstone crosscuts creek

Modelled Resistivity projected up 30m

Looking south



Oakdean

Even in the ox-bow lake, resistive sediment inferred to be sand with fresh water extends only about 15m deep. Beneath it seems likely that only Cretaceous coal seams exist. They have lower permeability and restrict tidal influence on groundwater.

Tidal limit

Monopoly

Contents

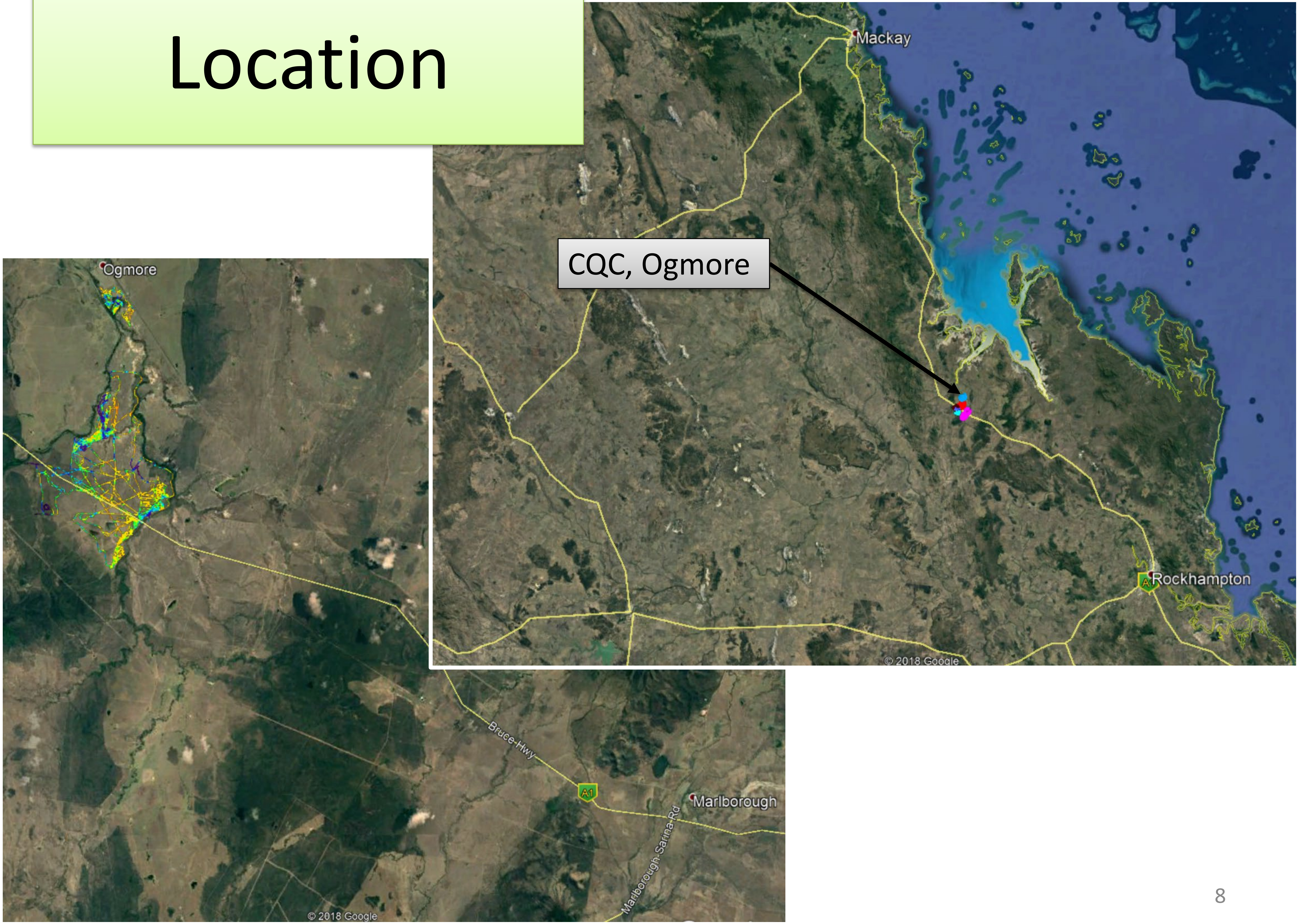
Context and Aim

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

Method Summary

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

Location



CQC, Ogmore

Geophysical Methods Introduction

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

Why use Electrical Conductivity Imaging for Groundwater Investigation

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

LOW EC

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

HIGH EC

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

Background information

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

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

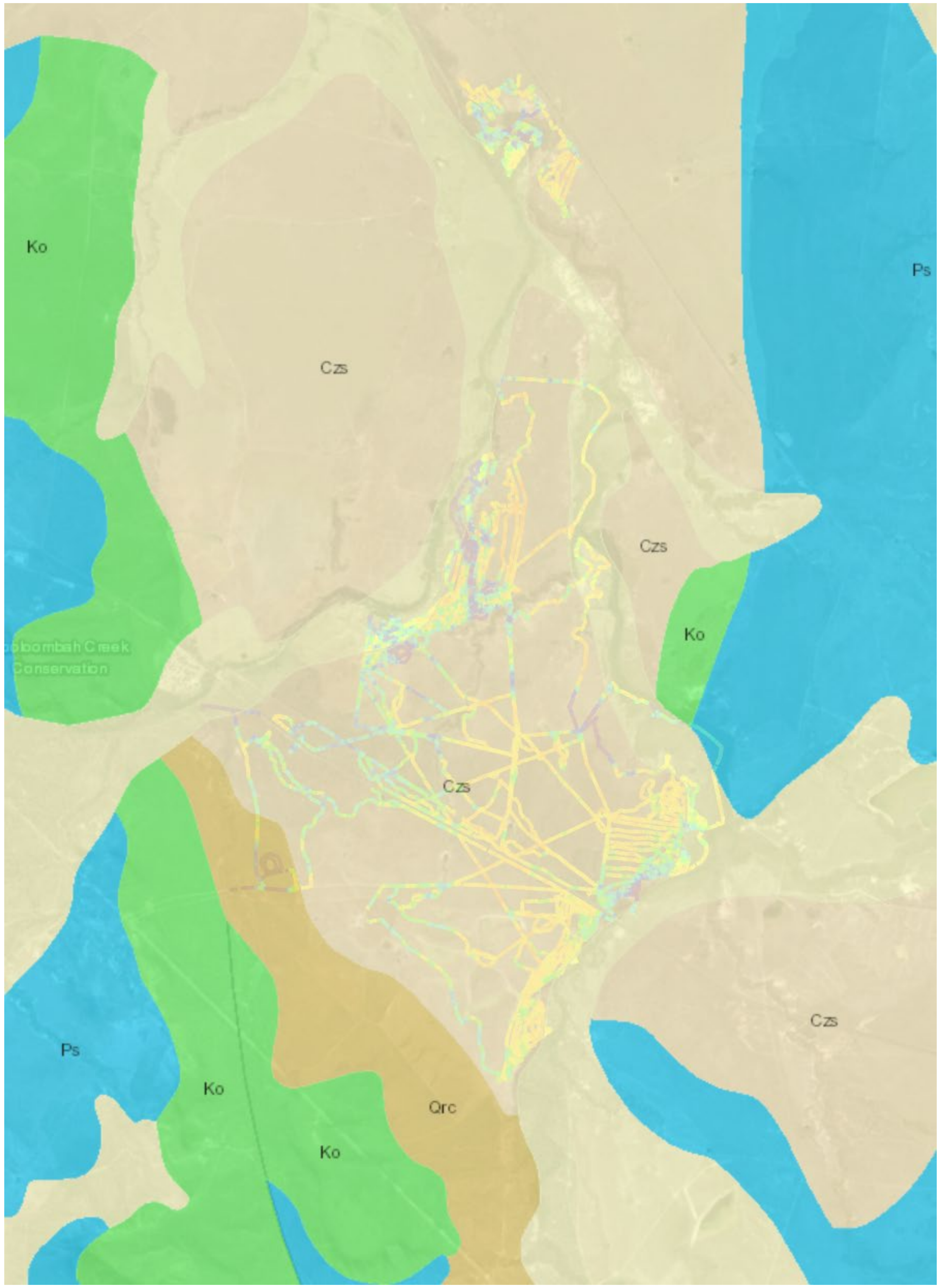
Some float resembling igneous dyke rock was found on the elevated plains but no dykes or sills were identified.

Government geological mapping comparison

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

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

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



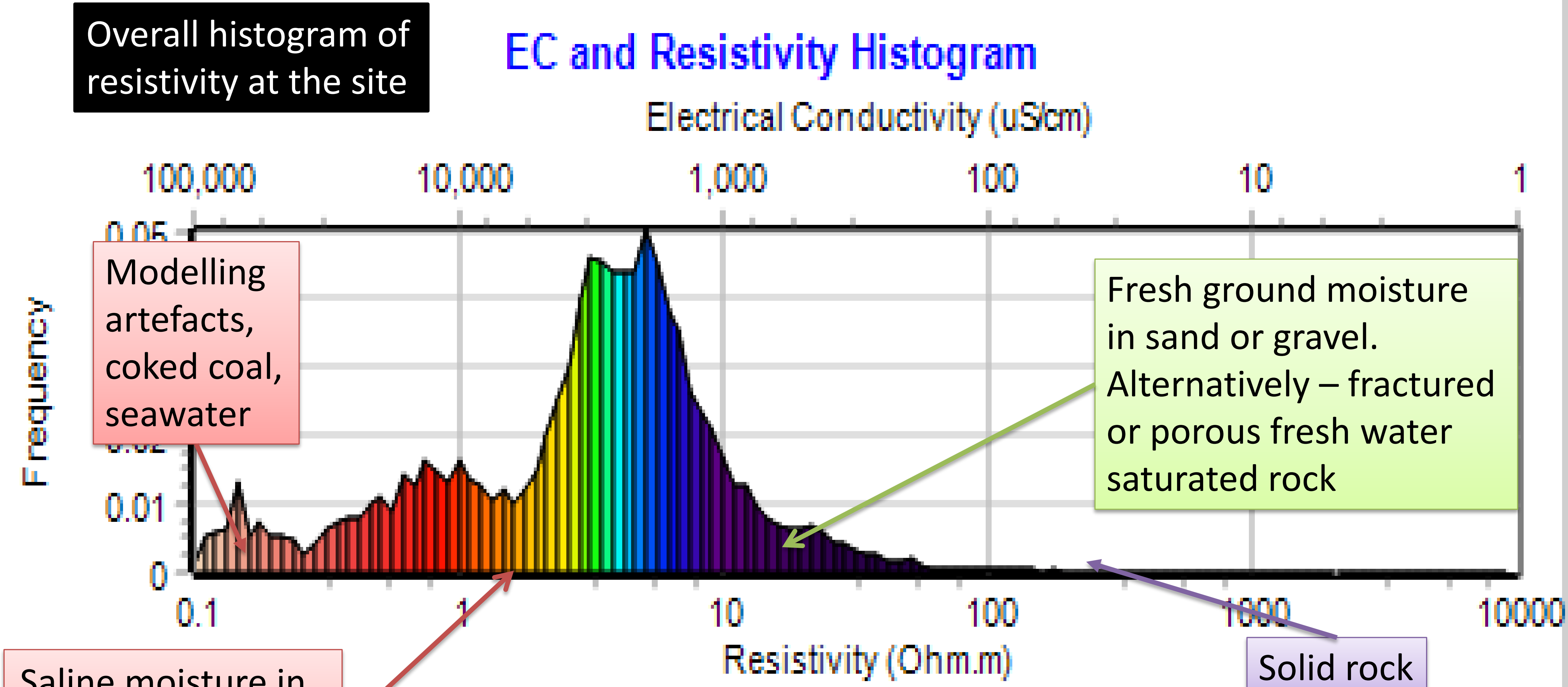
Results Presentation

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

Resistivity scale used in Google Earth Images

The inverse of Resistivity is Electrical Conductivity (EC).

Overall histogram of resistivity at the site



Modelling artefacts, coked coal, seawater

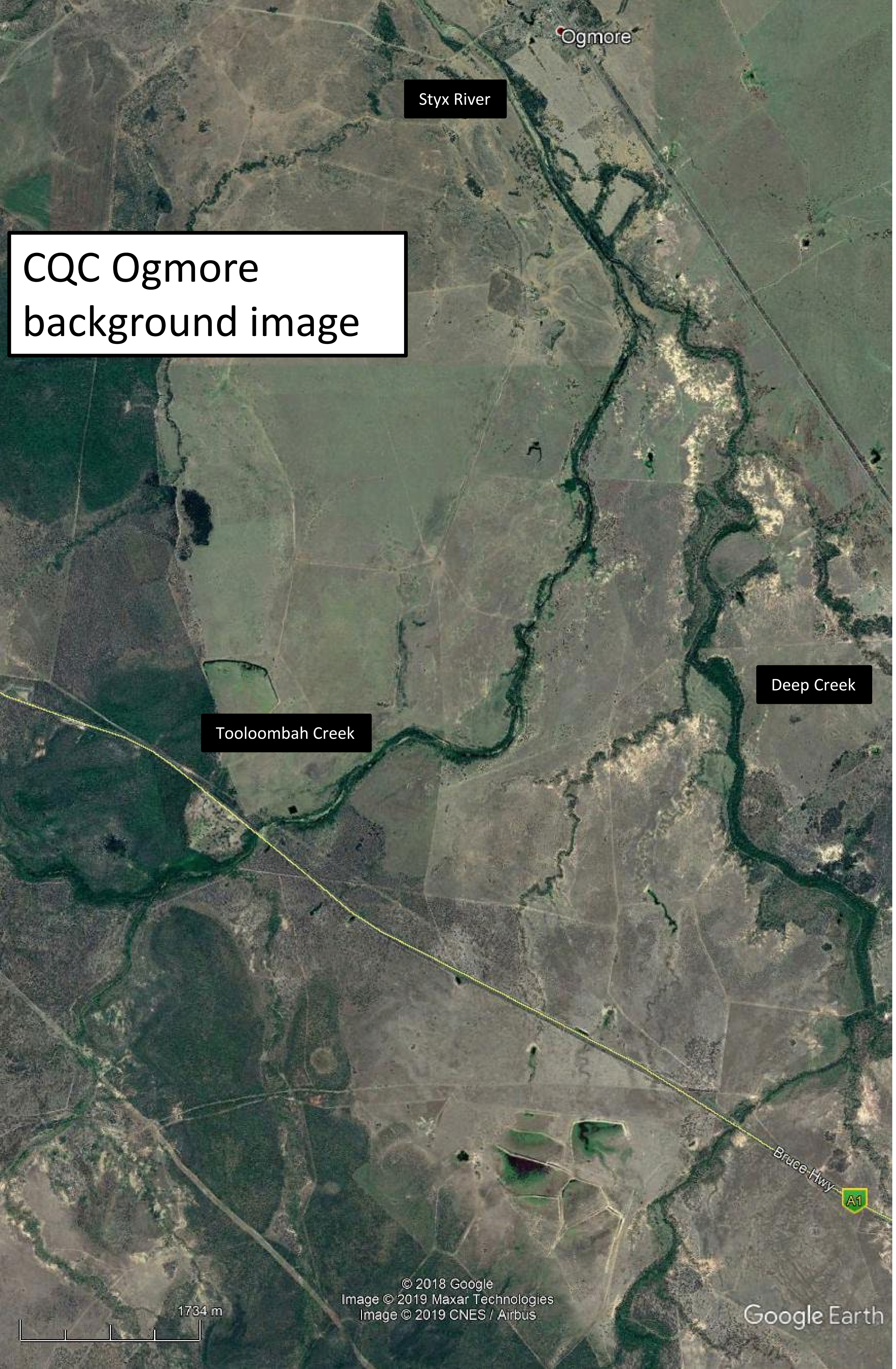
Fresh ground moisture in sand or gravel. Alternatively – fractured or porous fresh water saturated rock

Saline moisture in weathered rock and clay

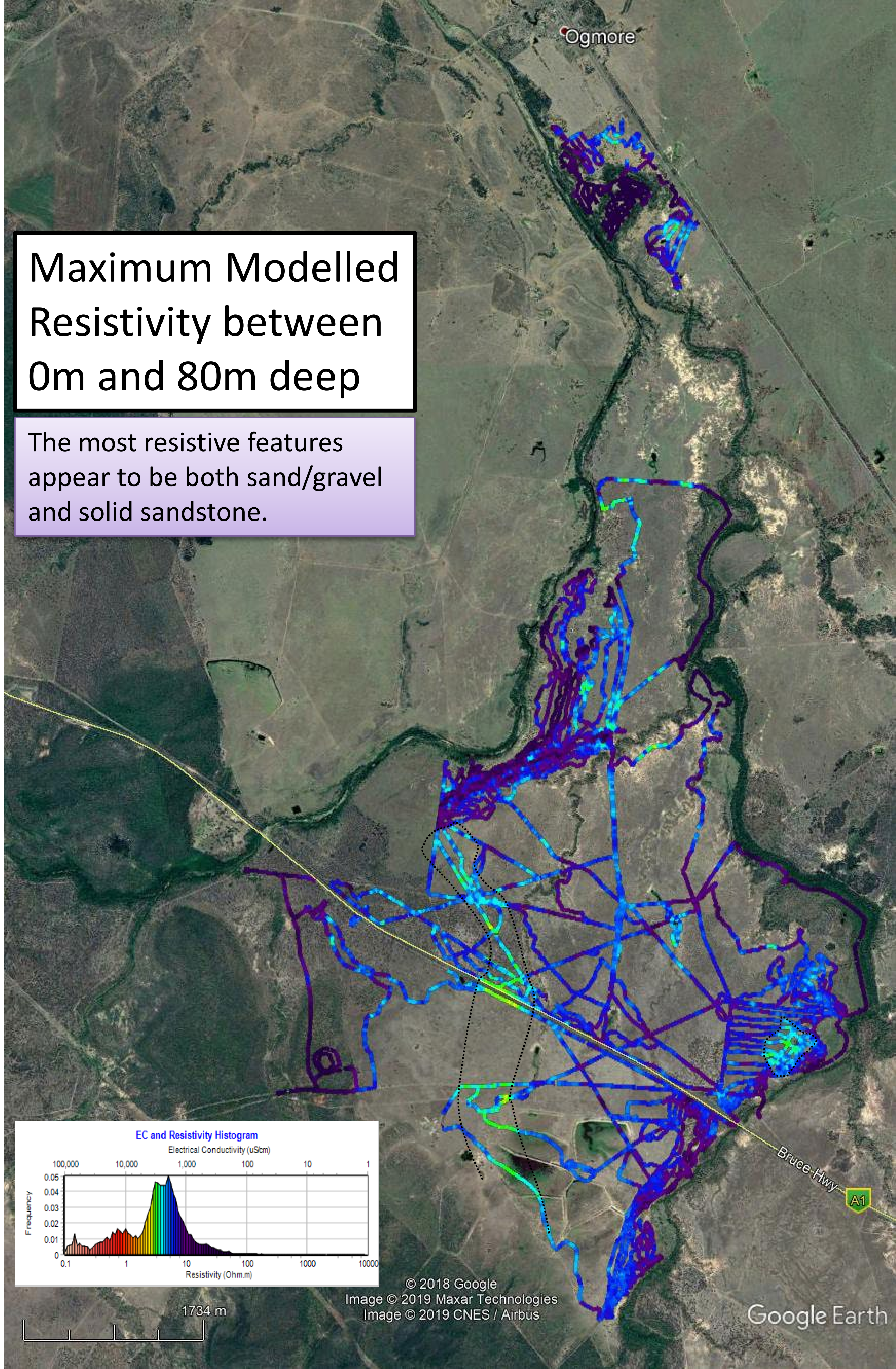
Solid rock

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

Full set of depth slices with common colour stretch

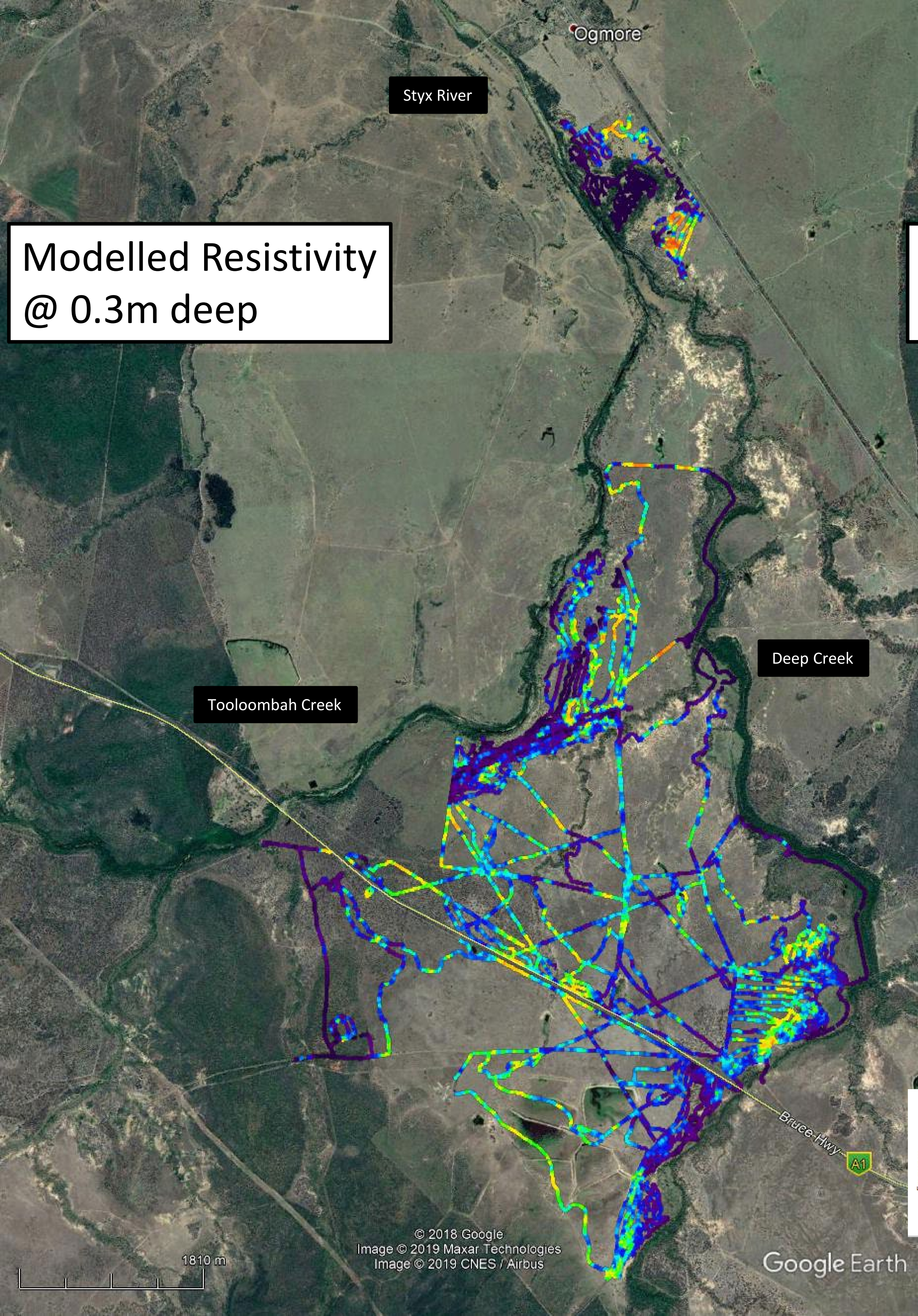


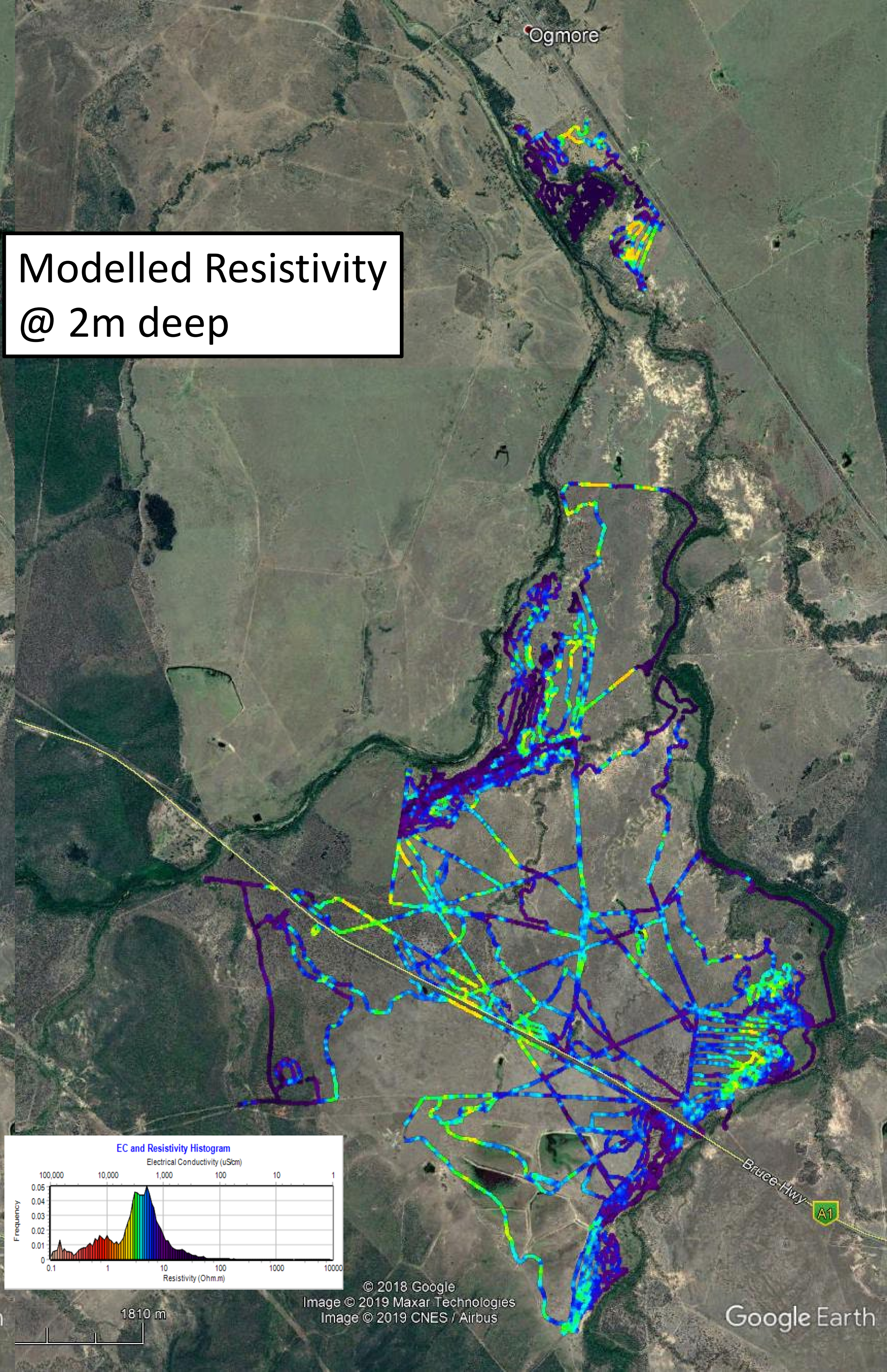
CQC Ogmore background image

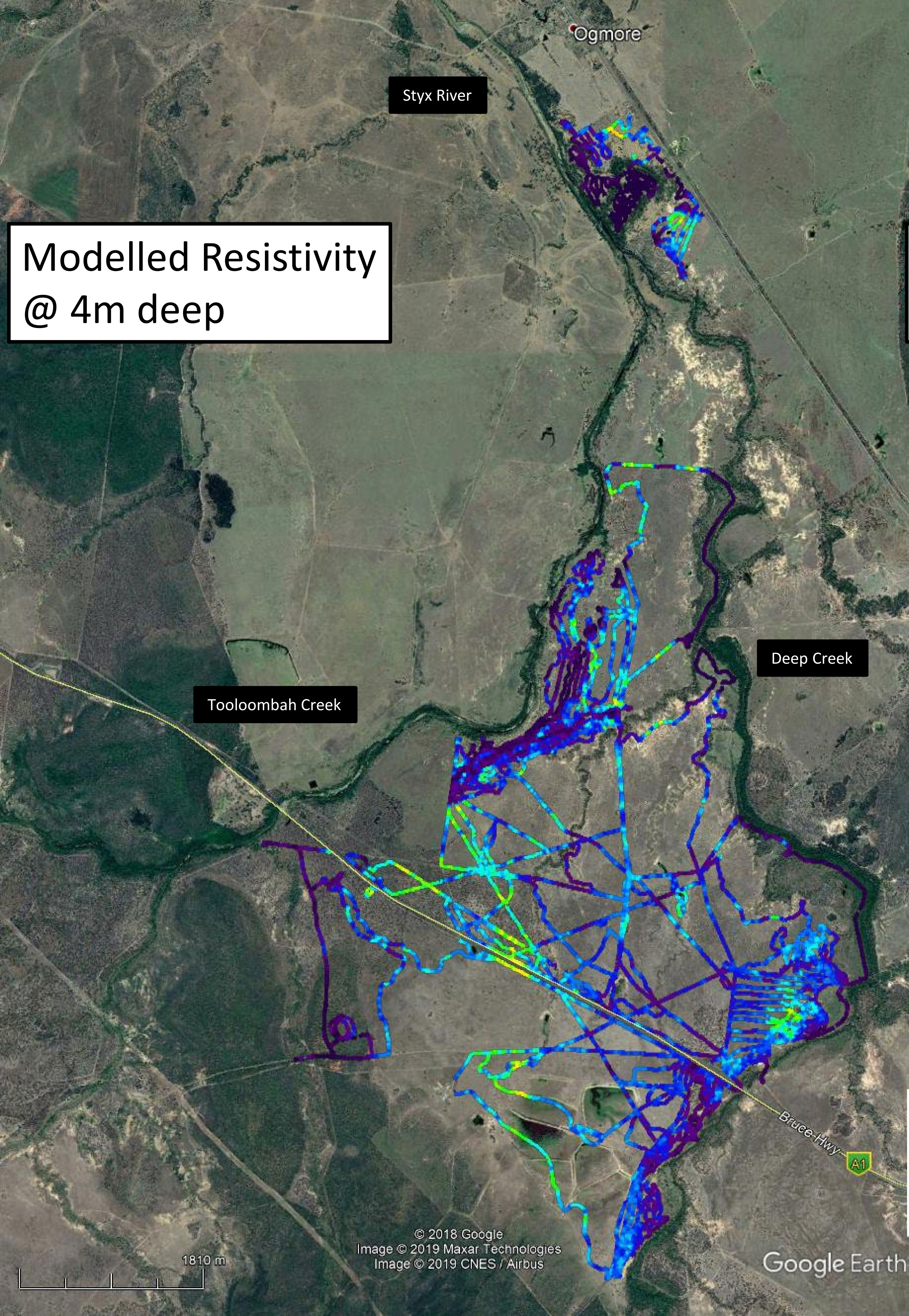


Maximum Modelled Resistivity between 0m and 80m deep

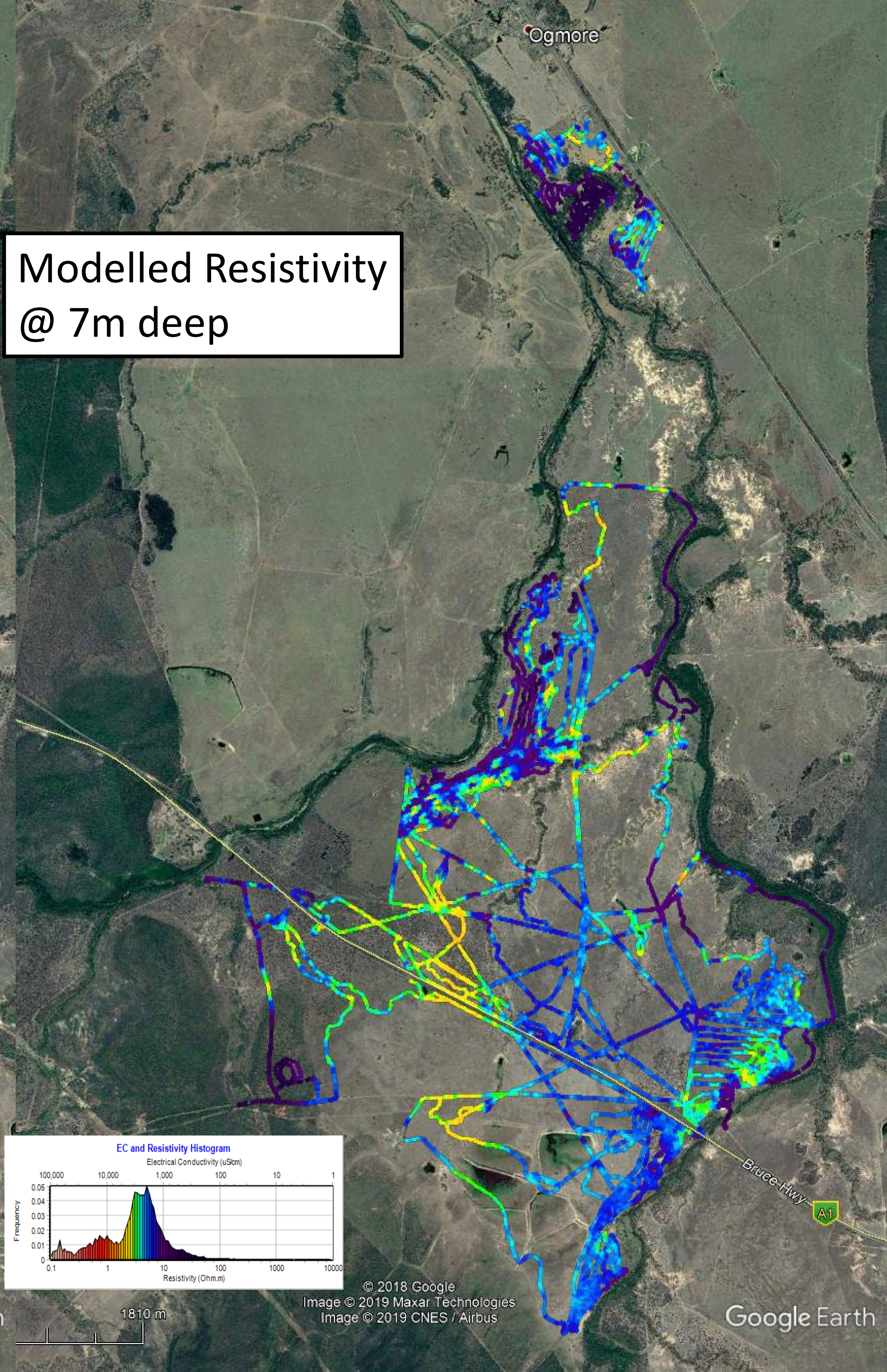
The most resistive features appear to be both sand/gravel and solid sandstone.


Ogmore
Styx River
Modelled Resistivity @ 0.3m deep
Deep Creek
Tooloombah Creek
Bruce Hwy
A1
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
1810 m
Google Earth

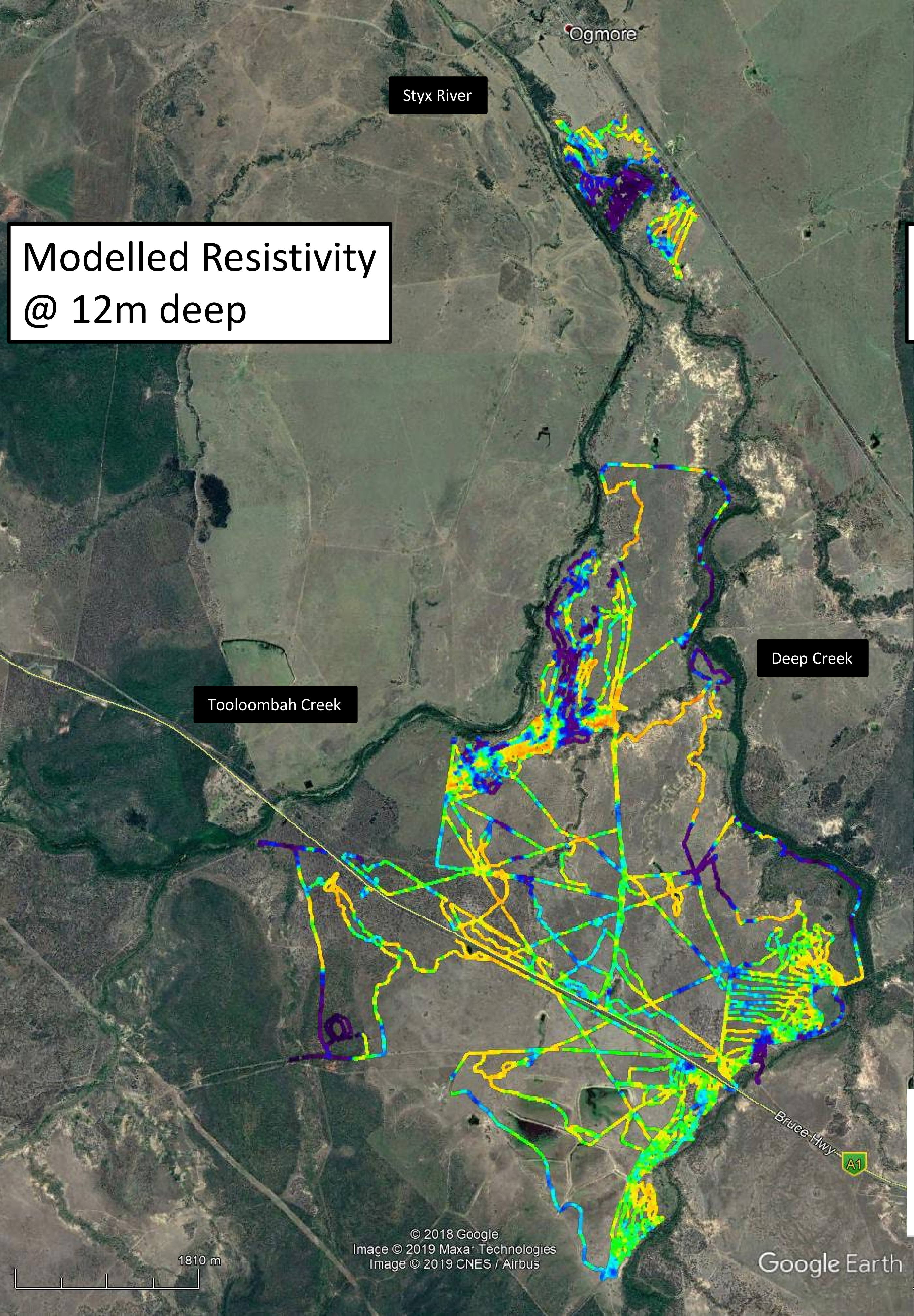

Ogmore
Modelled Resistivity @ 2m deep
EC and Resistivity Histogram
Electrical Conductivity (uS/cm)
100,000
10,000
1,000
100
10
1
Frequency
0.05
0.04
0.03
0.02
0.01
0
0.1
1
10
100
1000
10000
Resistivity (Ohm.m)
Bruce Hwy
A1
© 2018 Google
Image © 2019 Maxar Technologies
Image © 2019 CNES / Airbus
1810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



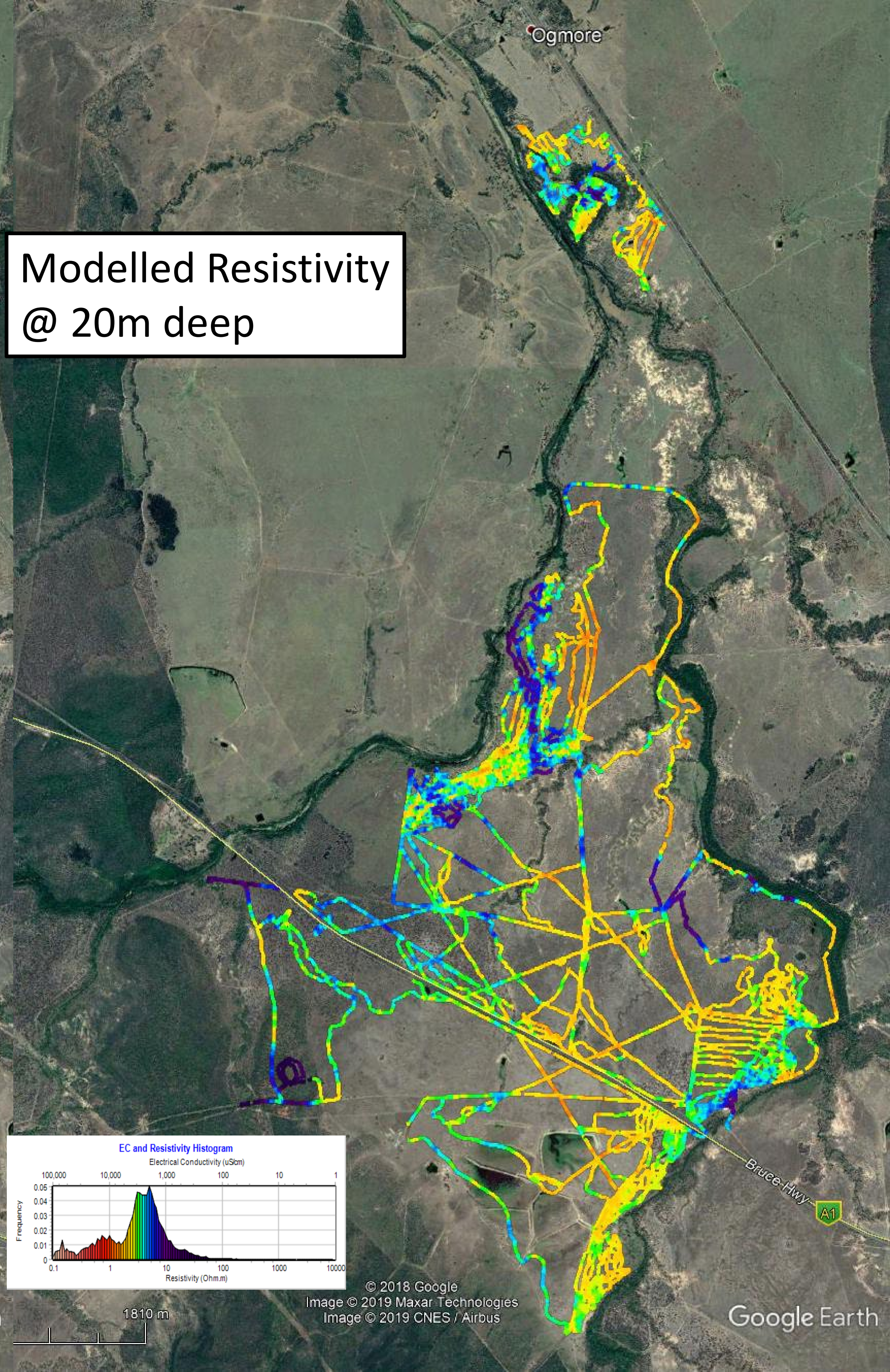
Modelled Resistivity @ 4m deep



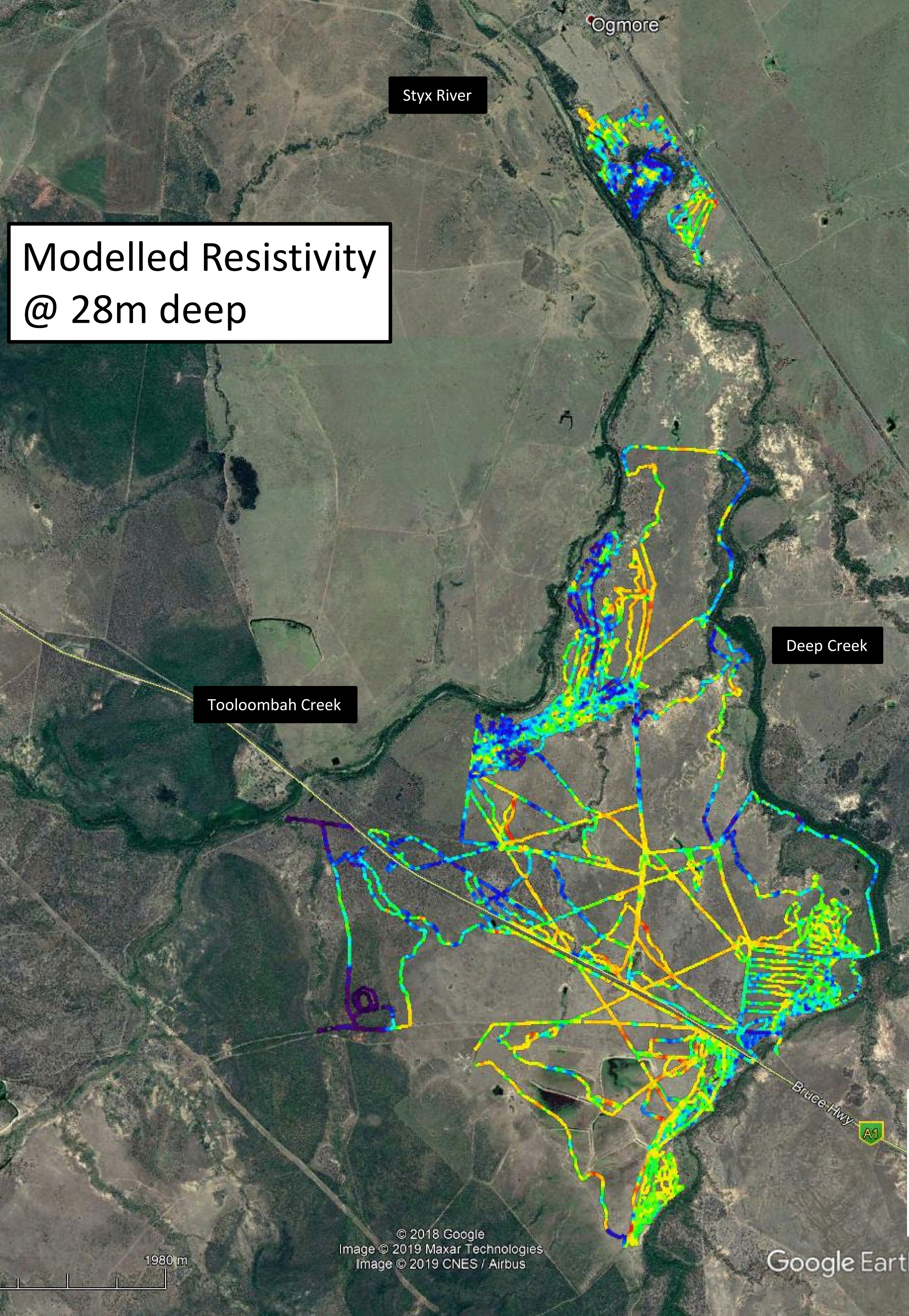
Modelled Resistivity @ 7m deep



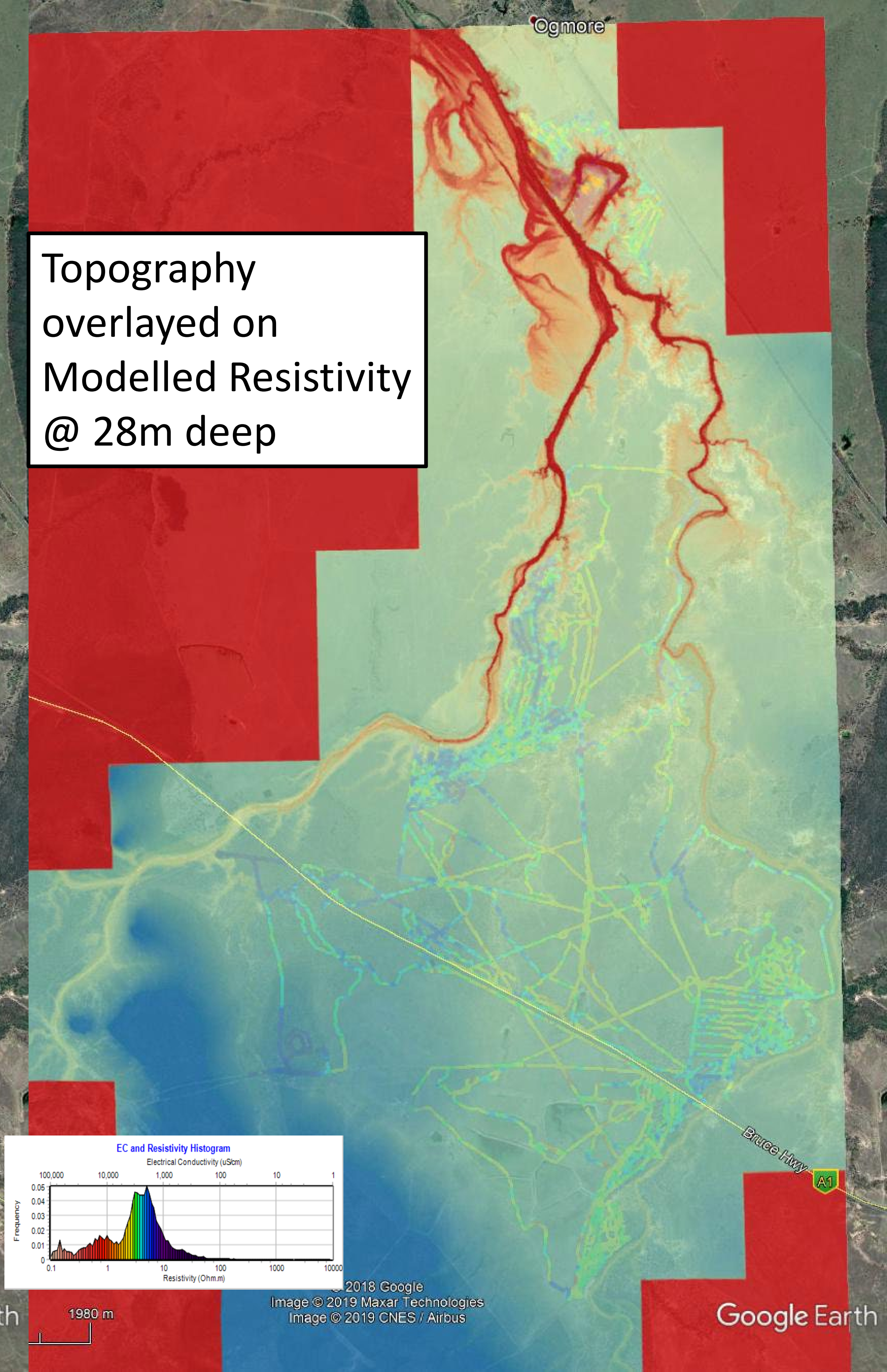
Modelled Resistivity @ 12m deep



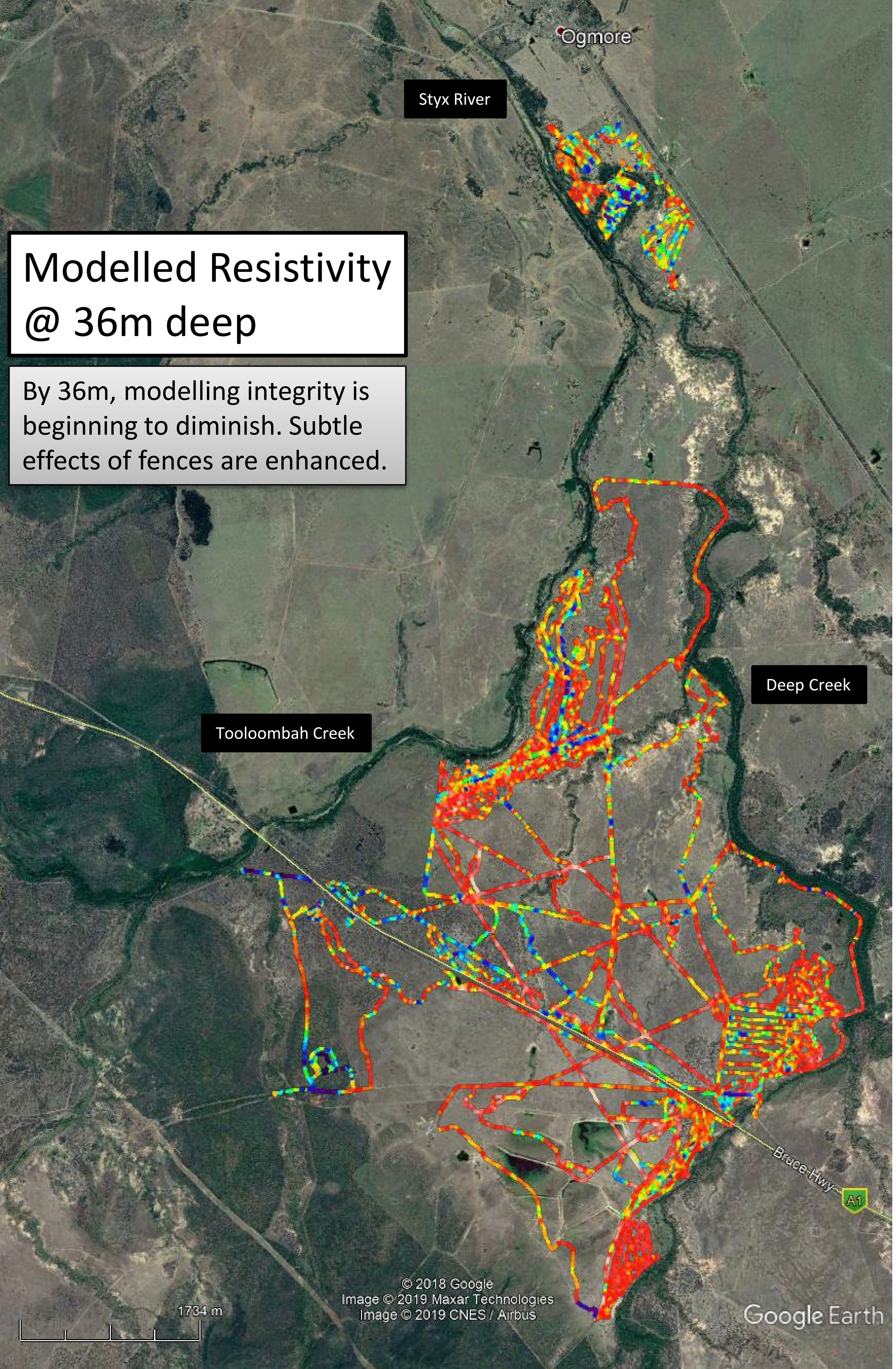
Modelled Resistivity @ 20m deep



Modelled Resistivity @ 28m deep

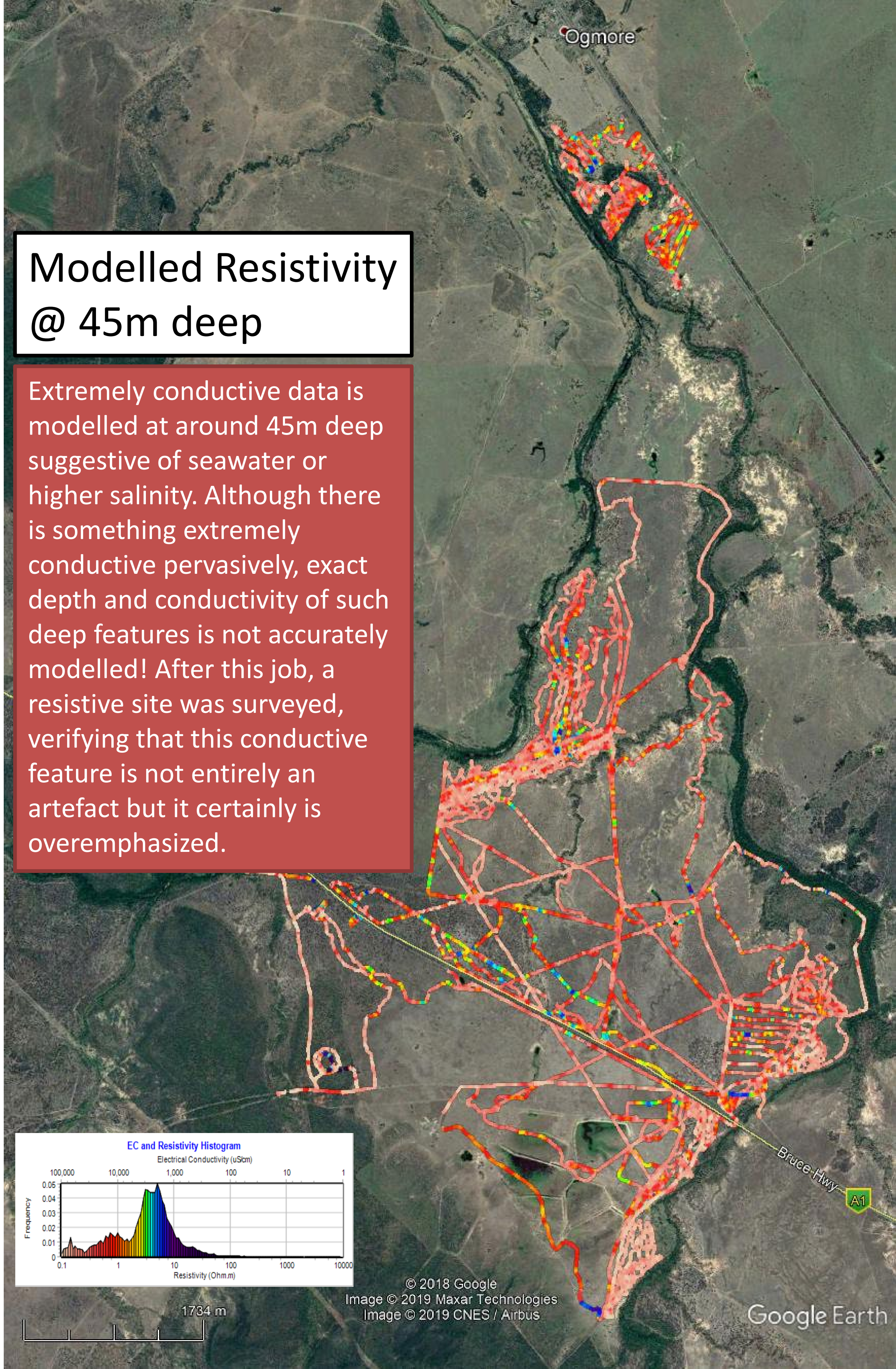


Topography overlayed on Modelled Resistivity @ 28m deep



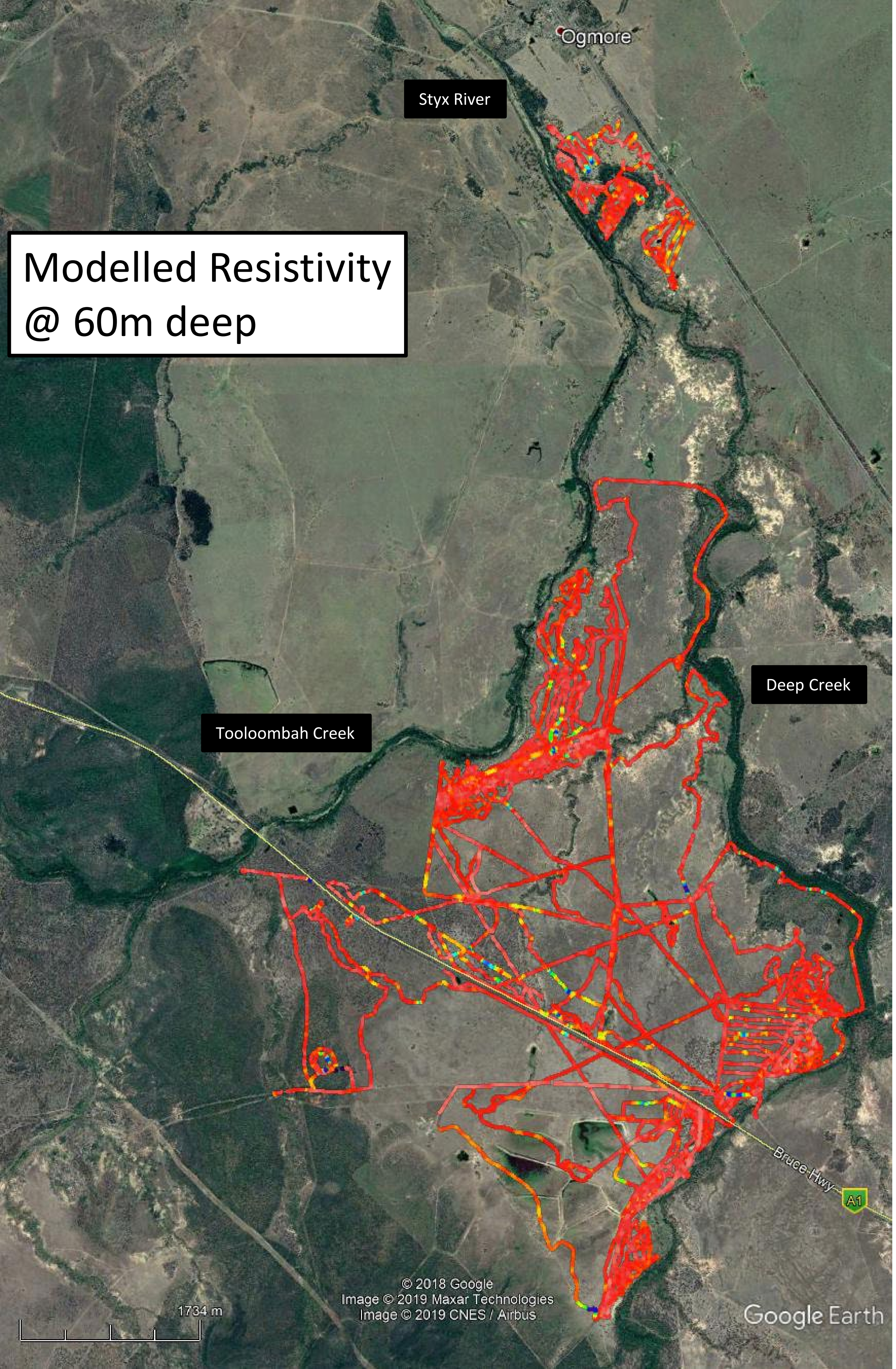
Modelled Resistivity @ 36m deep

By 36m, modelling integrity is beginning to diminish. Subtle effects of fences are enhanced.

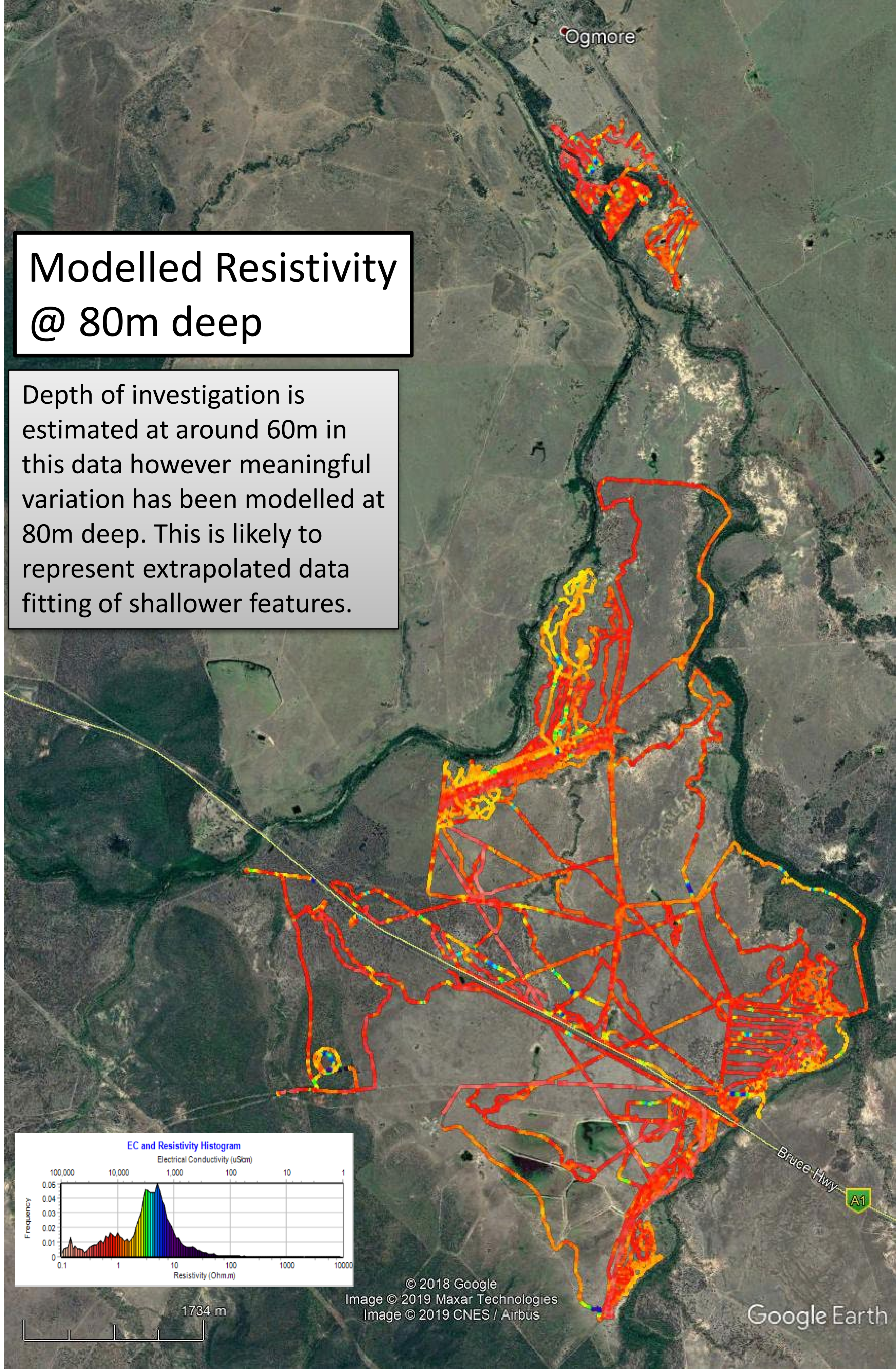


Modelled Resistivity @ 45m deep

Extremely conductive data is modelled at around 45m deep suggestive of seawater or higher salinity. Although there is something extremely conductive pervasively, exact depth and conductivity of such deep features is not accurately modelled! After this job, a resistive site was surveyed, verifying that this conductive feature is not entirely an artefact but it certainly is overemphasized.



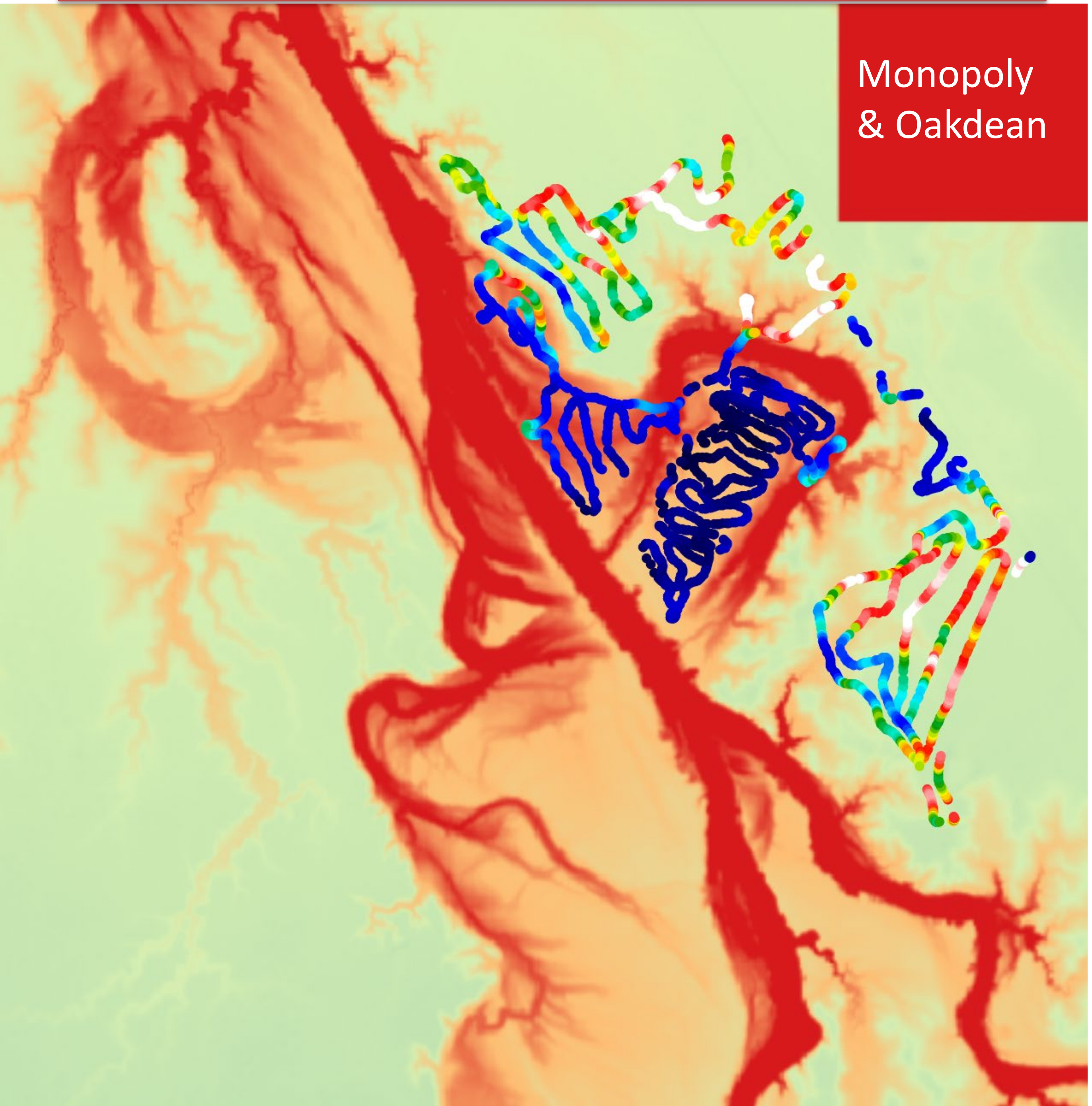
Modelled Resistivity @ 60m deep



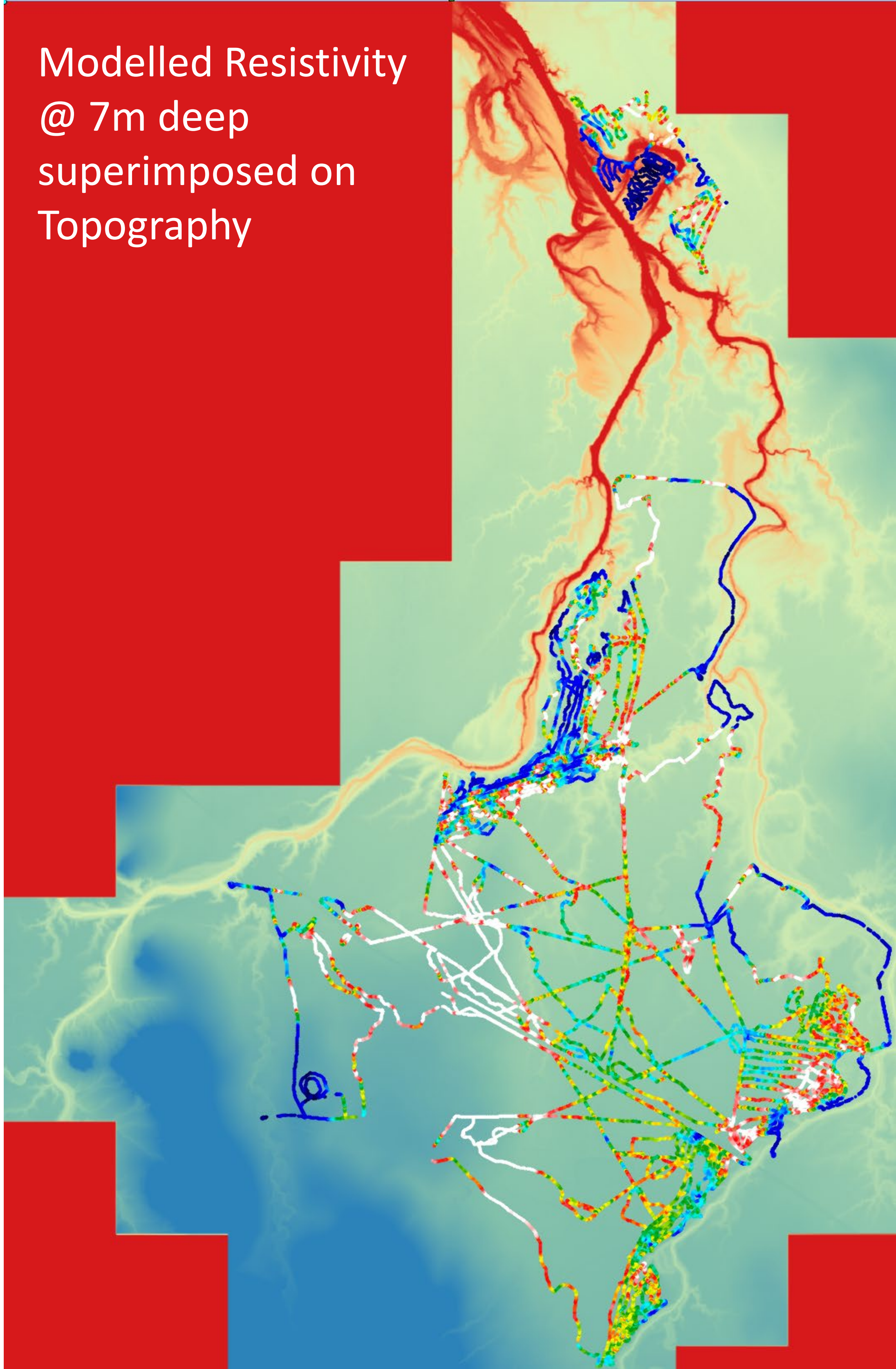
Modelled Resistivity @ 80m deep

Depth of investigation is estimated at around 60m in this data however meaningful variation has been modelled at 80m deep. This is likely to represent extrapolated data fitting of shallower features.

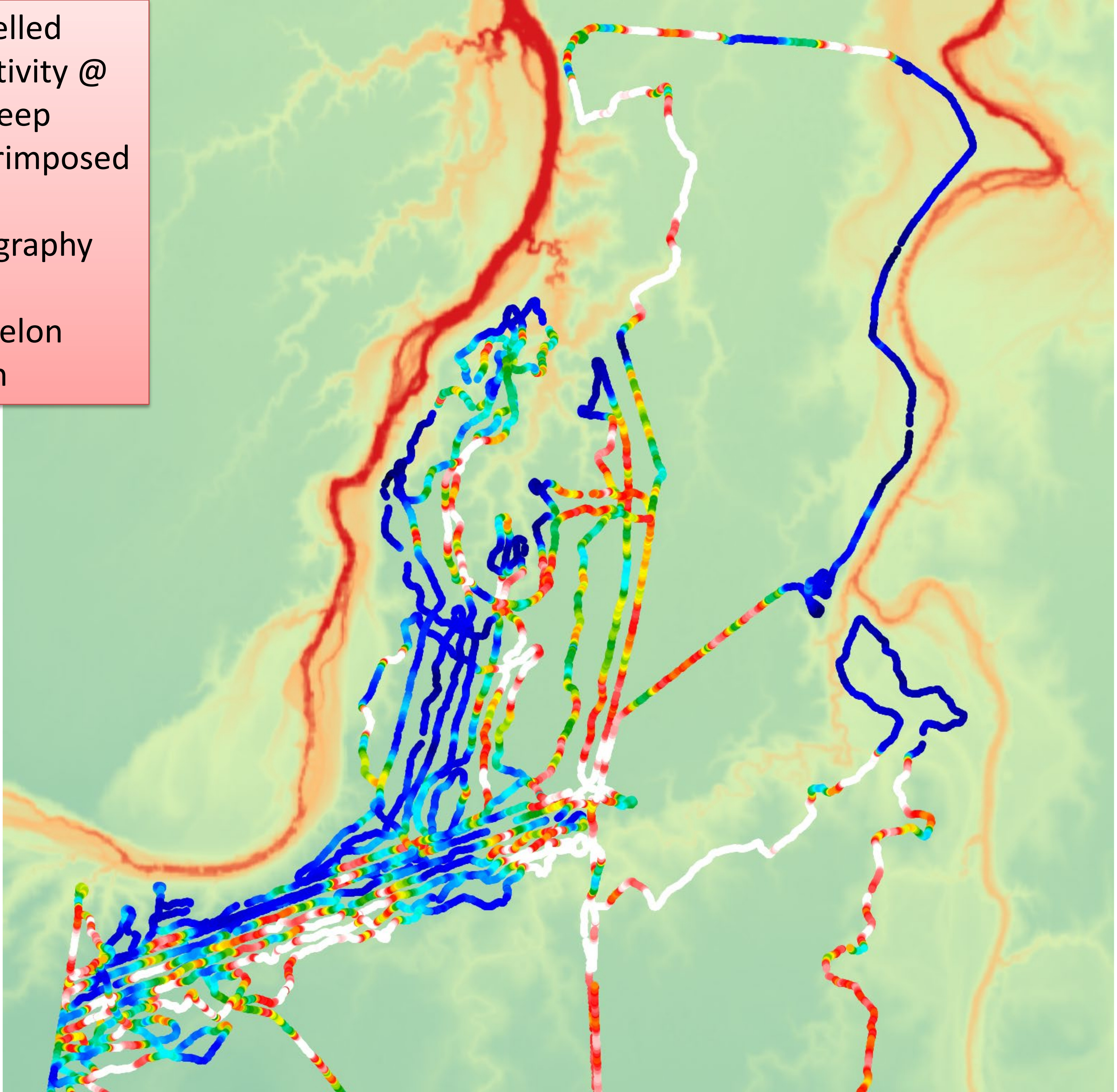
Comparison of topography with modelled resistivity at various depths reveals that some resistive features are associated with incised creeks, some are suggestive of infilled incised creeks and some cross-cut or are otherwise unrelated to the creeks. The unrelated ones seem to be thick sandstone.



Monopoly & Oakdean

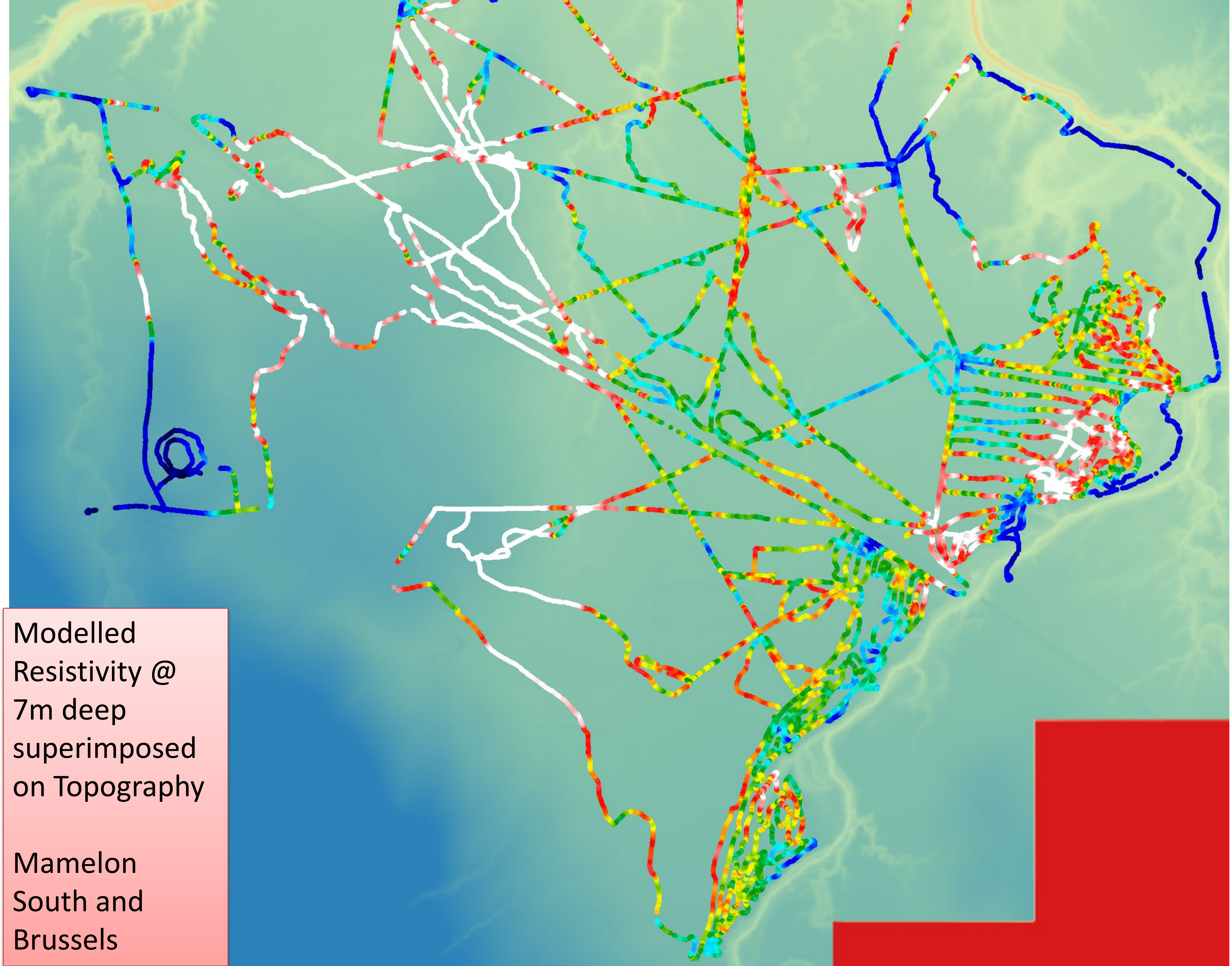


Modelled Resistivity @ 7m deep superimposed on Topography



Modelled Resistivity @ 7m deep superimposed on Topography

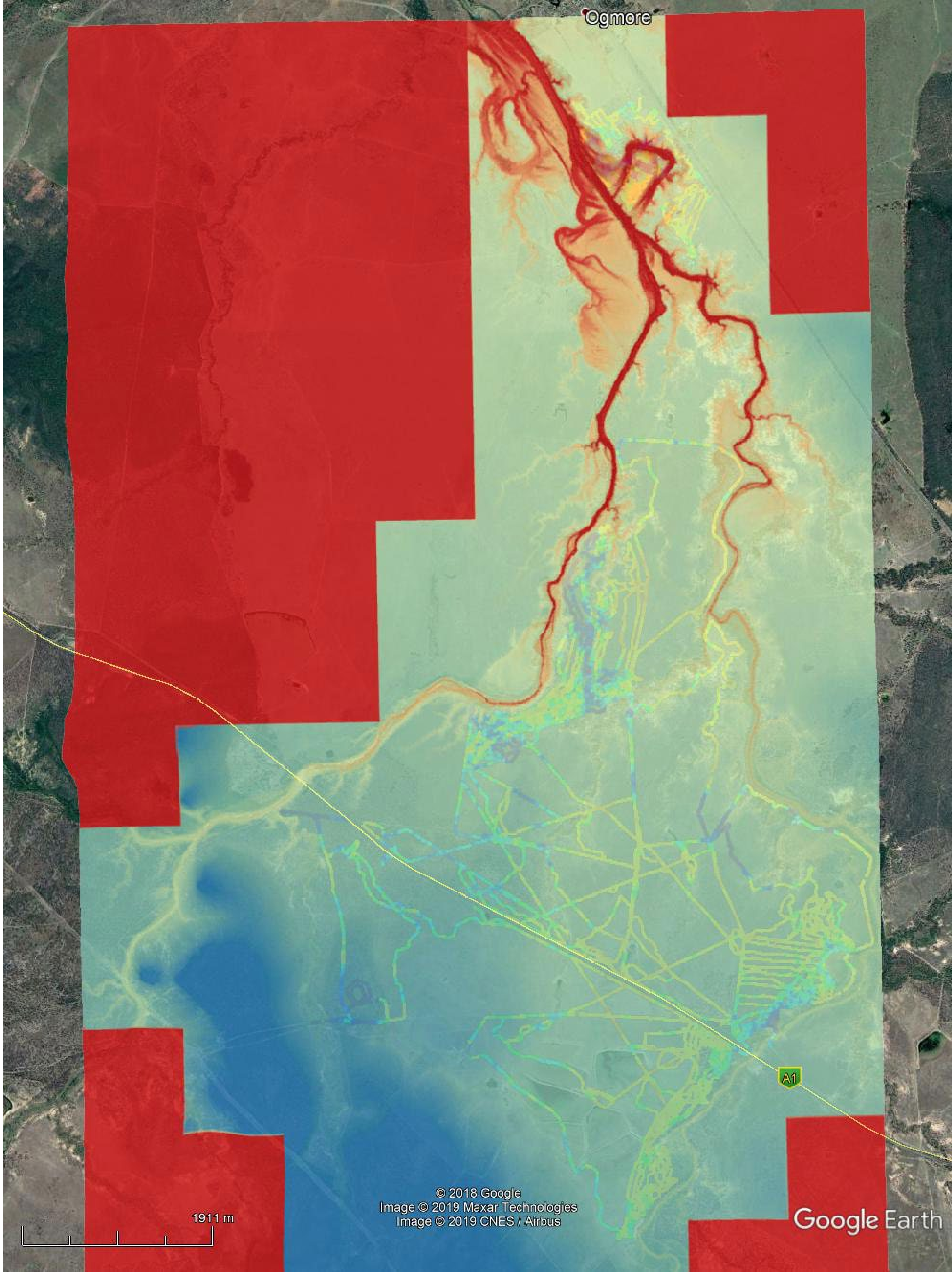
Mamelon North



Modelled Resistivity @ 7m deep superimposed on Topography

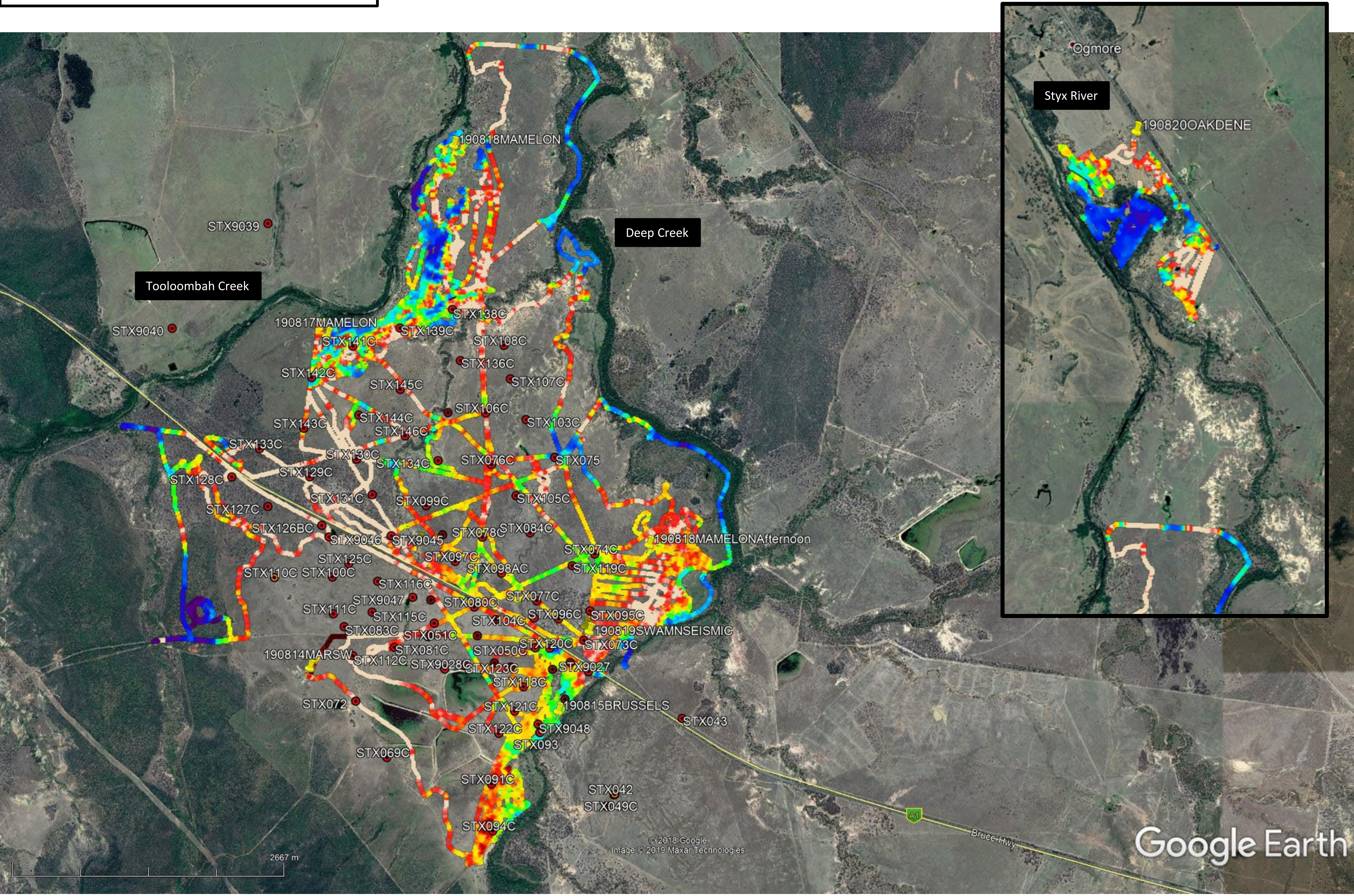
Mamelon South and Brussels

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

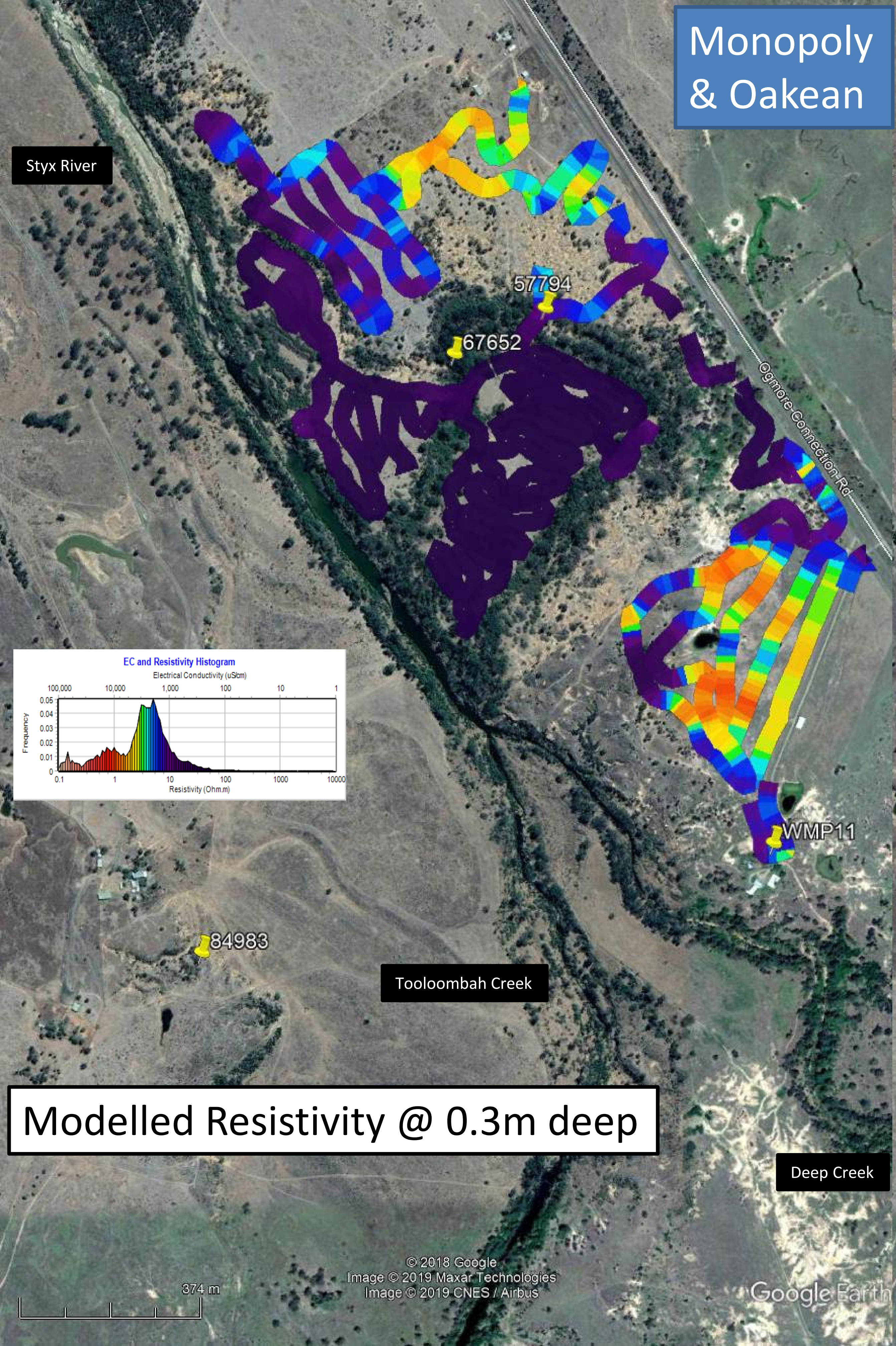


Raw Voltage Data gate 22

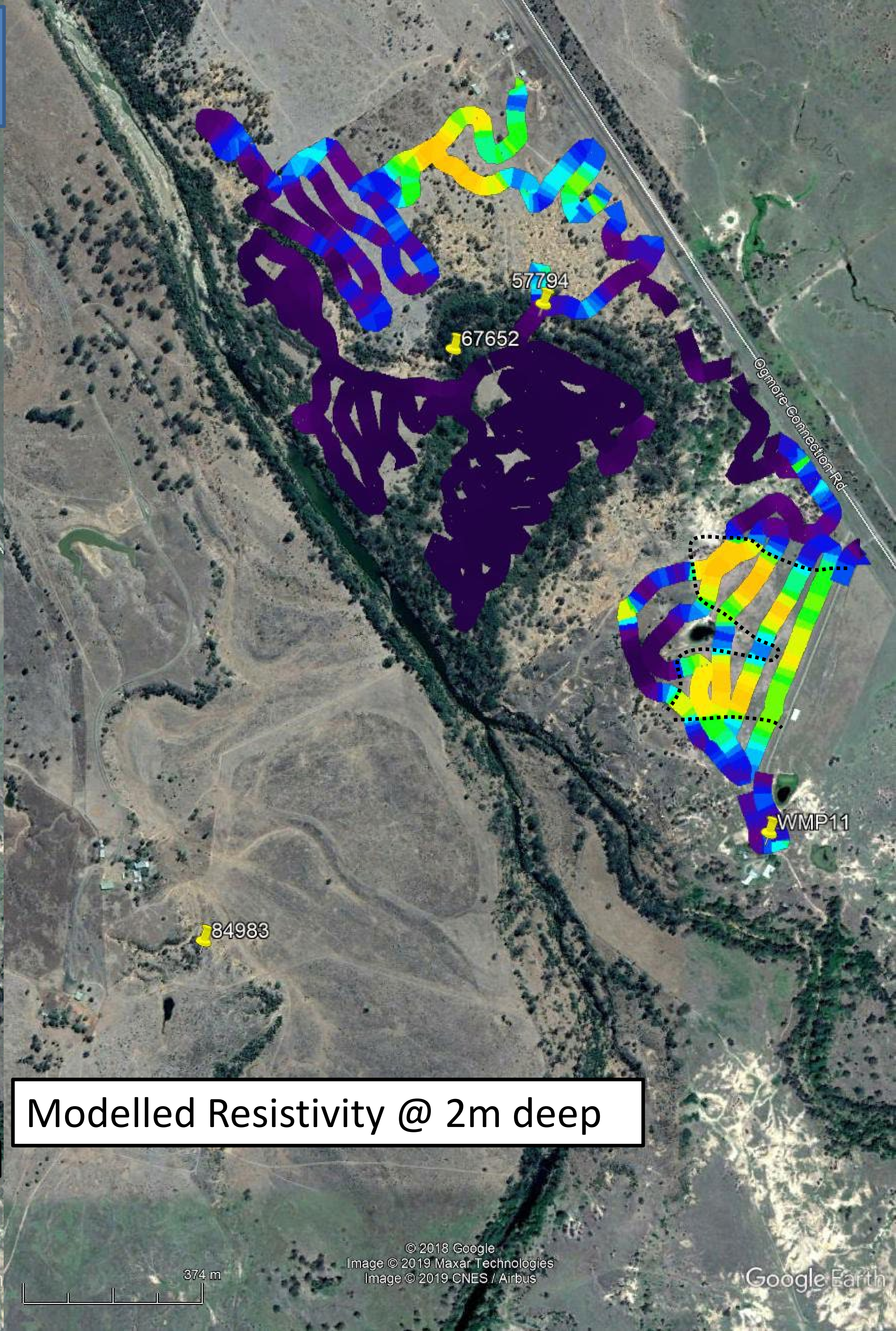
Raw voltage images are good at distinguishing depth to the shallowest non-resistive layer but generally mask anything beneath that layer



Monopoly & Oakean

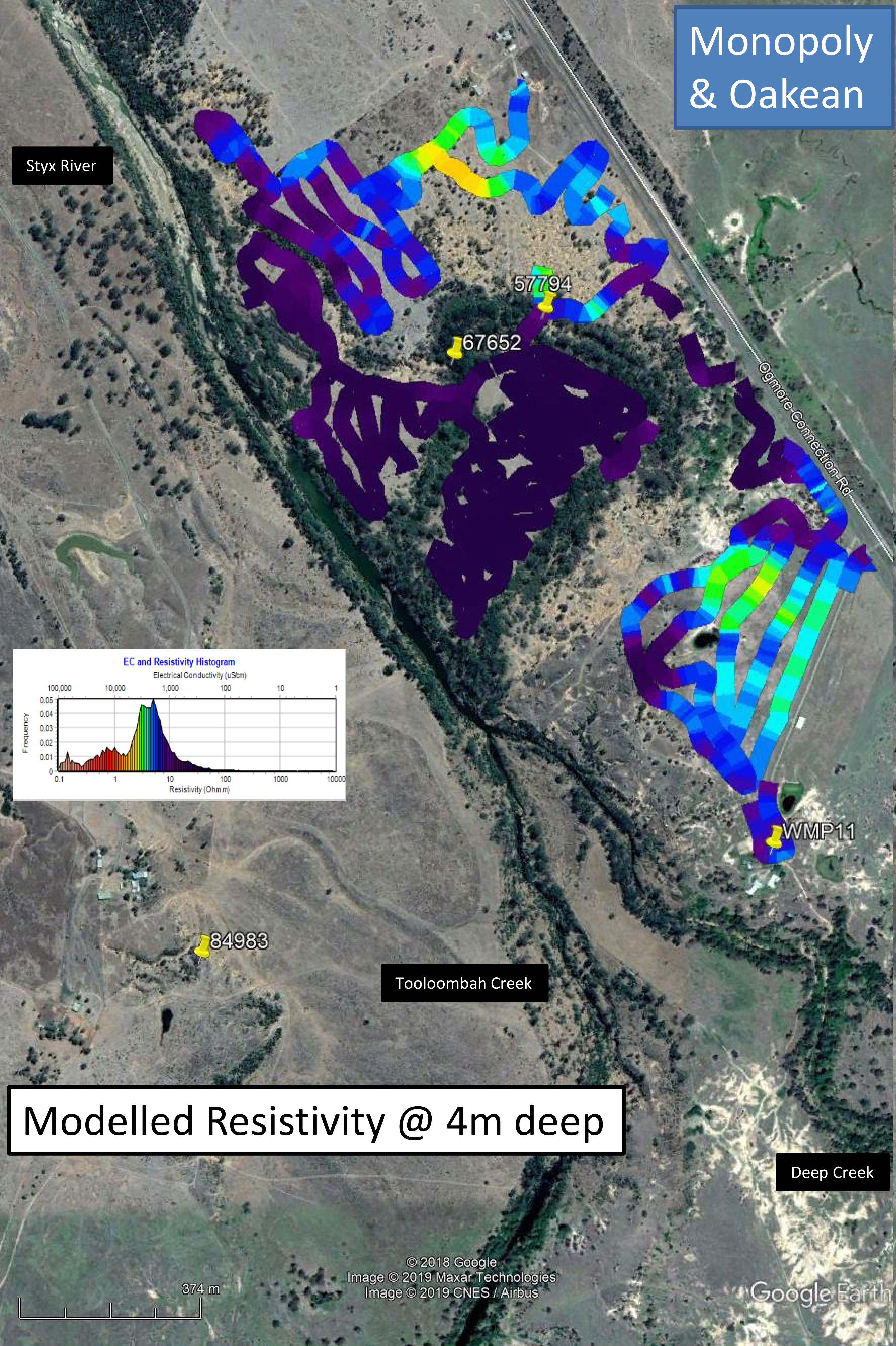


Modelled Resistivity @ 0.3m deep

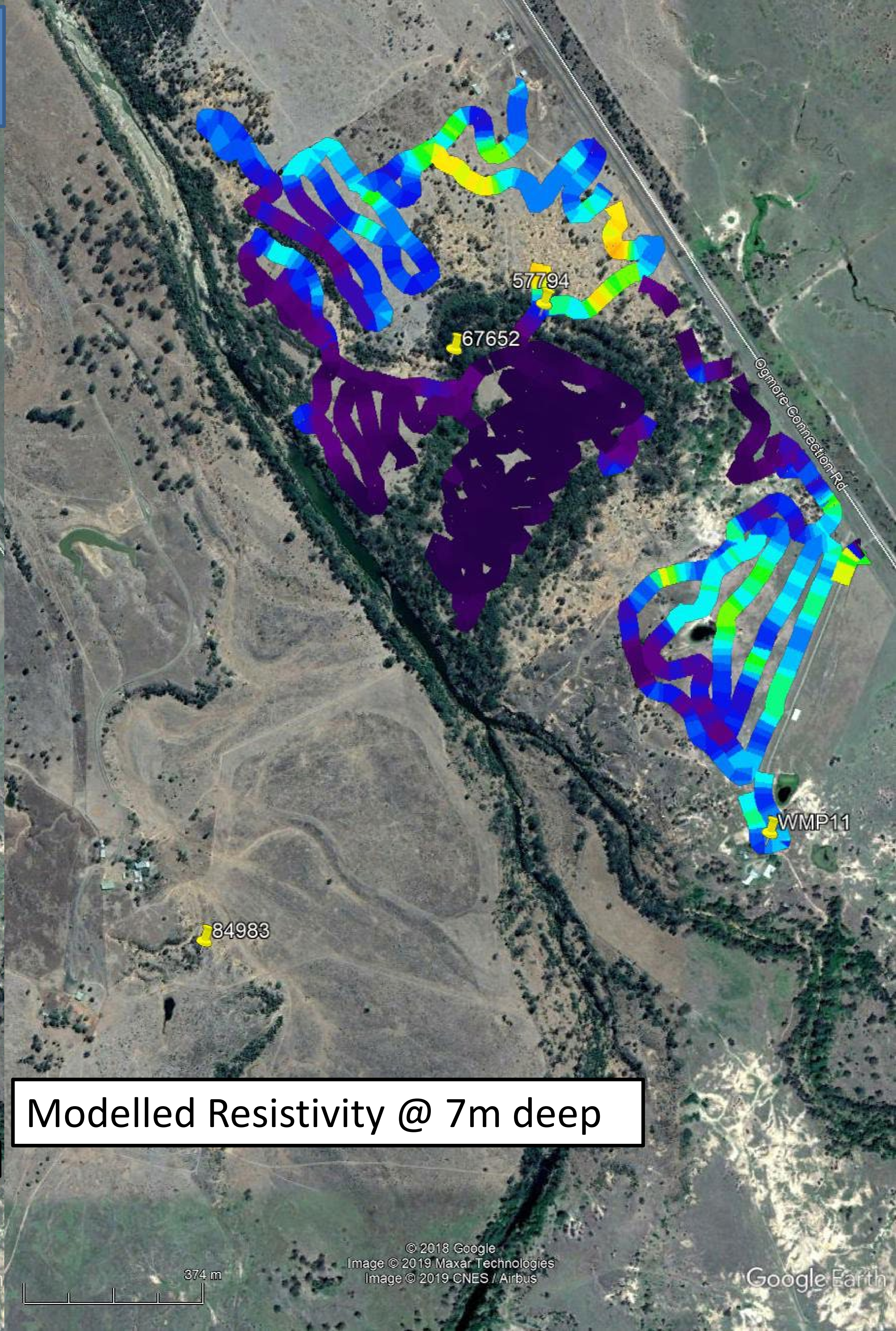


Modelled Resistivity @ 2m deep

Monopoly & Oakean

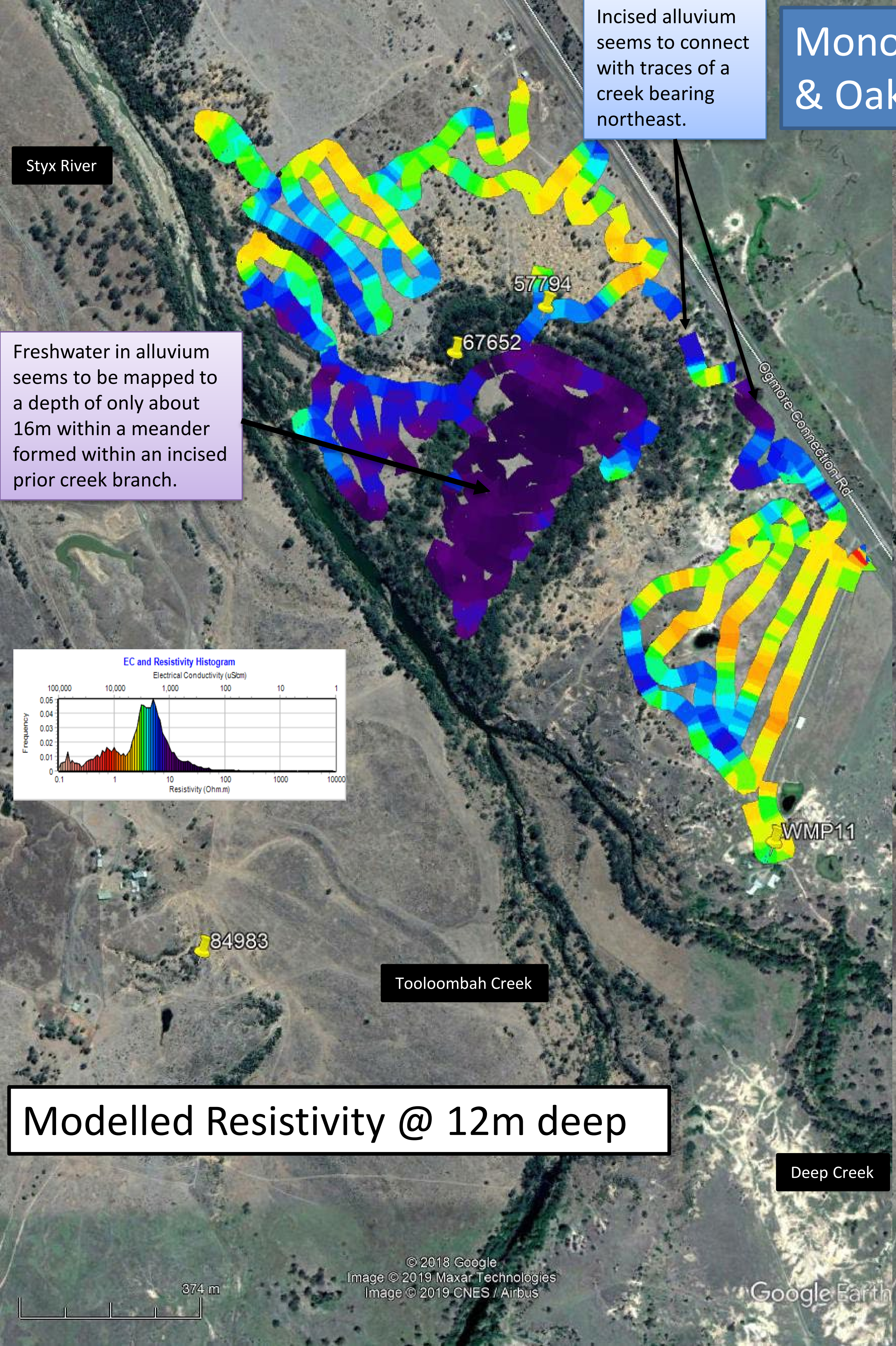


Modelled Resistivity @ 4m deep



Modelled Resistivity @ 7m deep

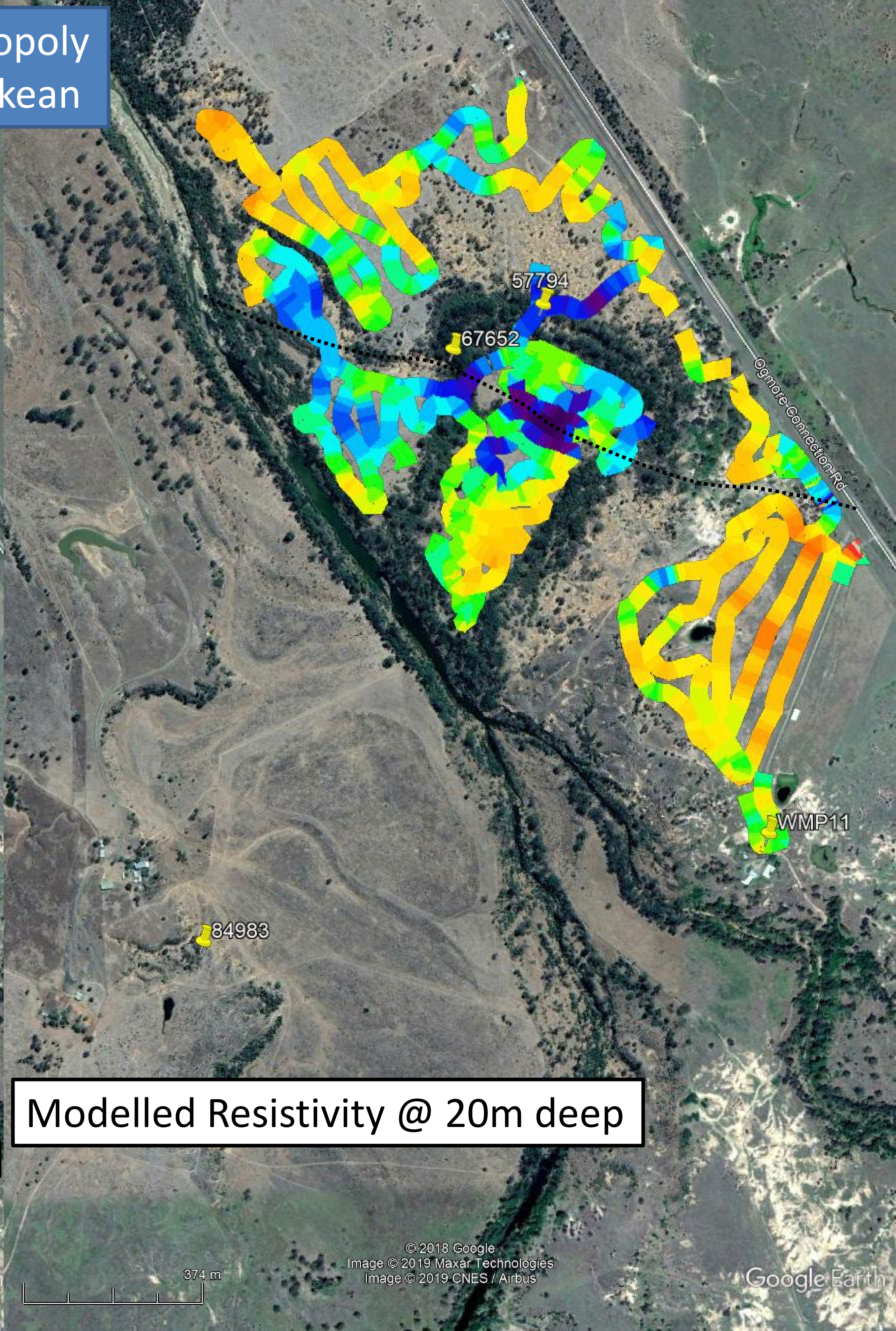
Monopoly & Oakean



Incised alluvium seems to connect with traces of a creek bearing northeast.

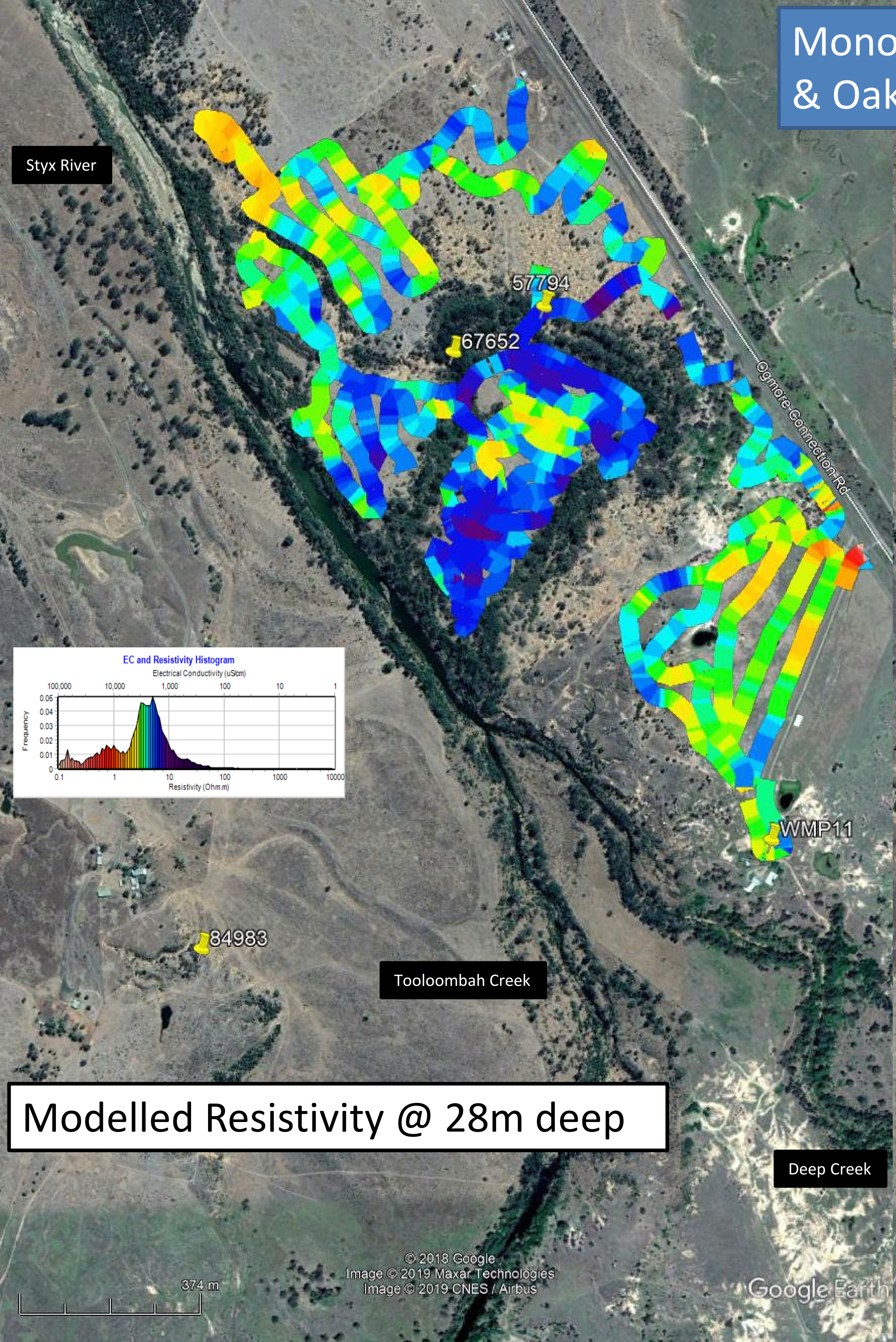
Freshwater in alluvium seems to be mapped to a depth of only about 16m within a meander formed within an incised prior creek branch.

Modelled Resistivity @ 12m deep

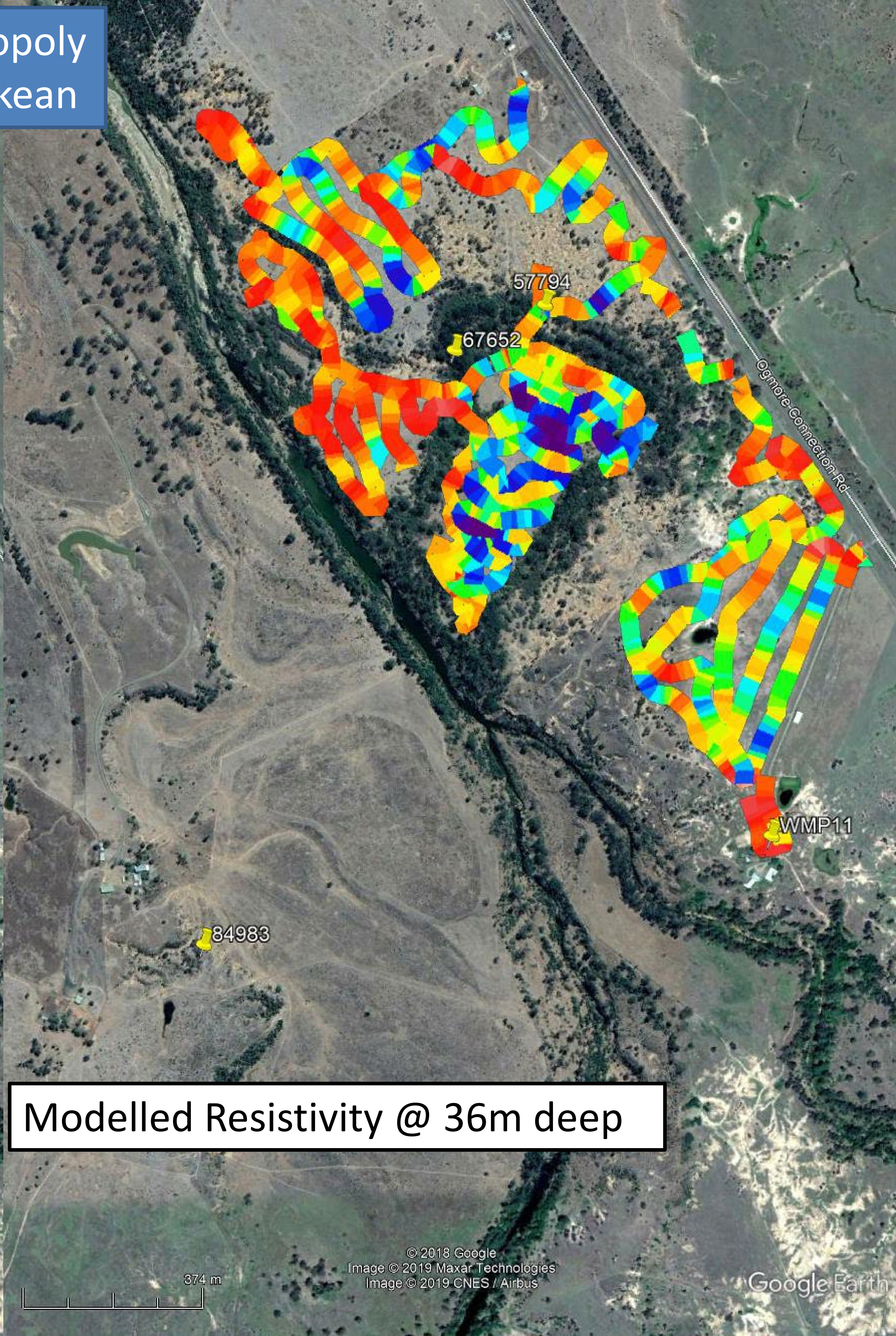


Modelled Resistivity @ 20m deep

Monopoly & Oakean



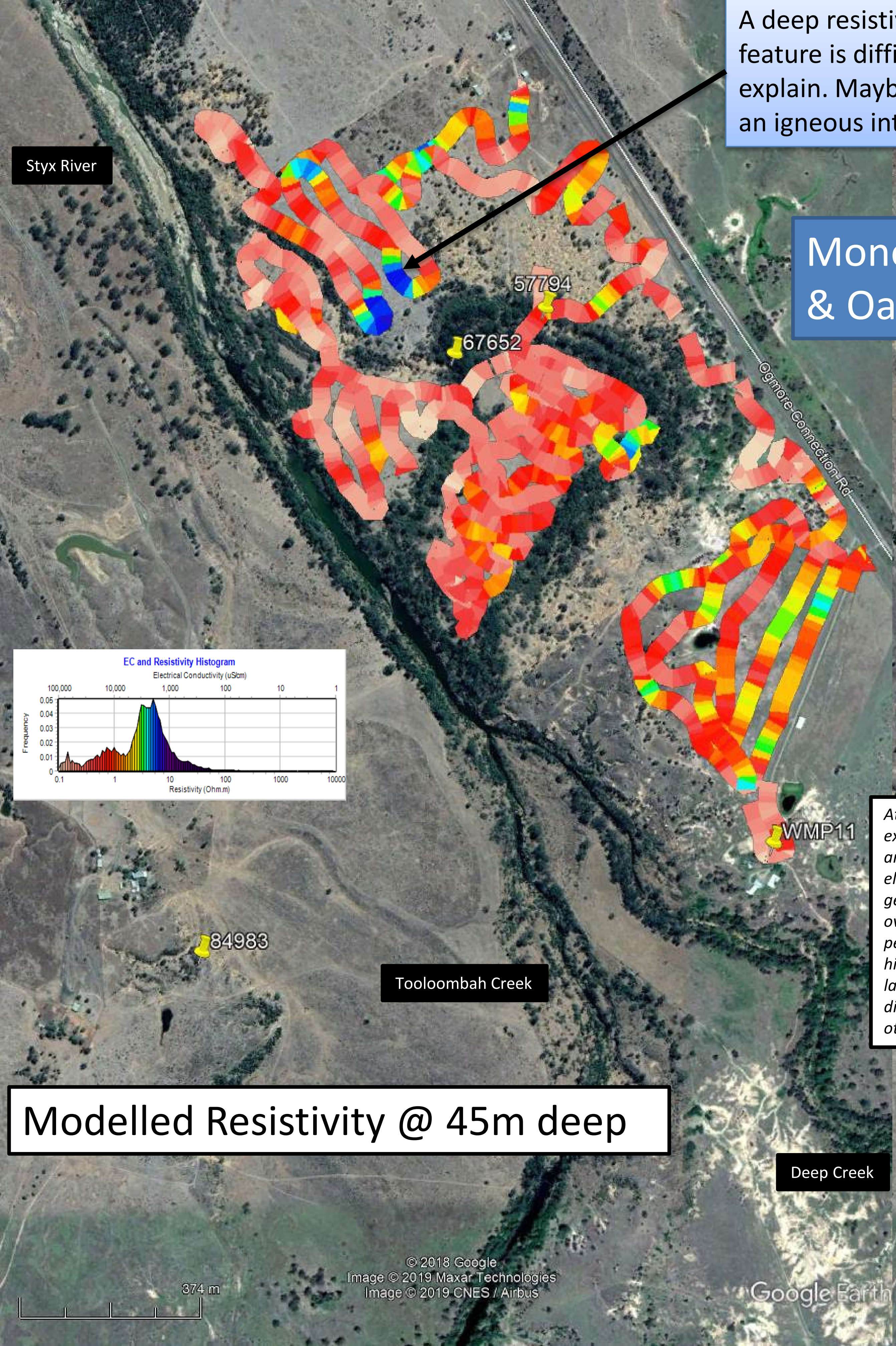
Modelled Resistivity @ 28m deep



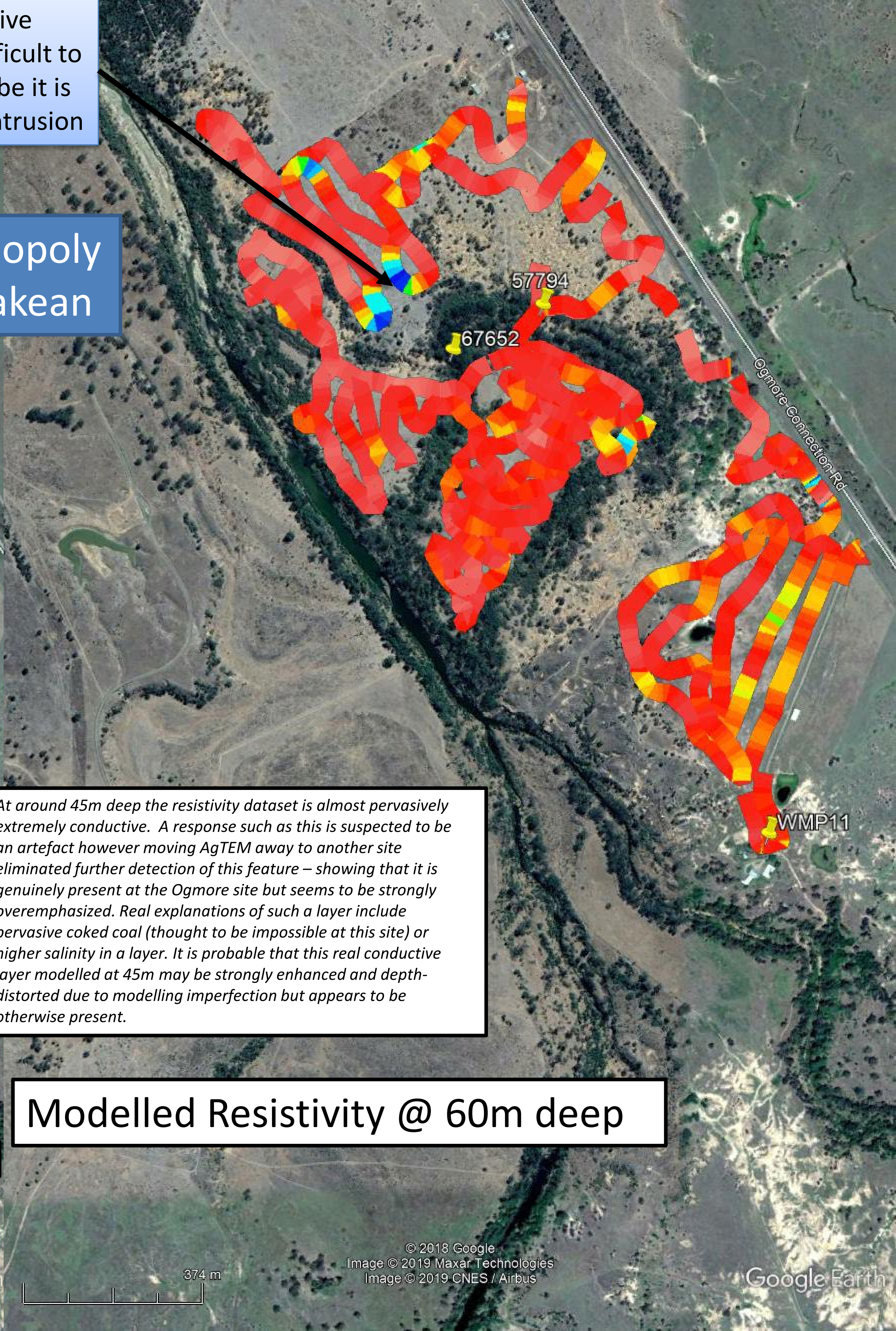
Modelled Resistivity @ 36m deep

Monopoly & Oakean

A deep resistive feature is difficult to explain. Maybe it is an igneous intrusion



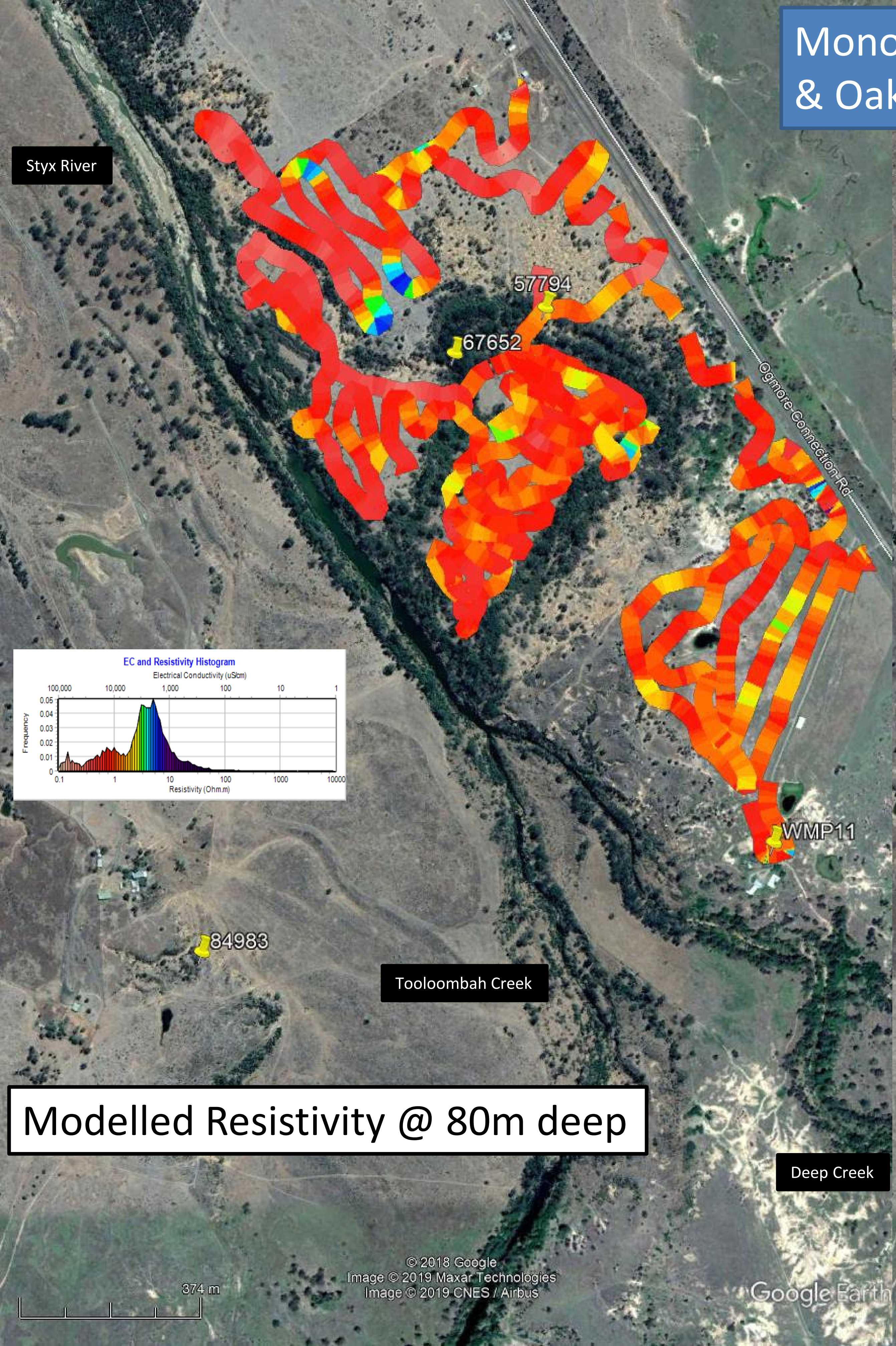
Modelled Resistivity @ 45m deep



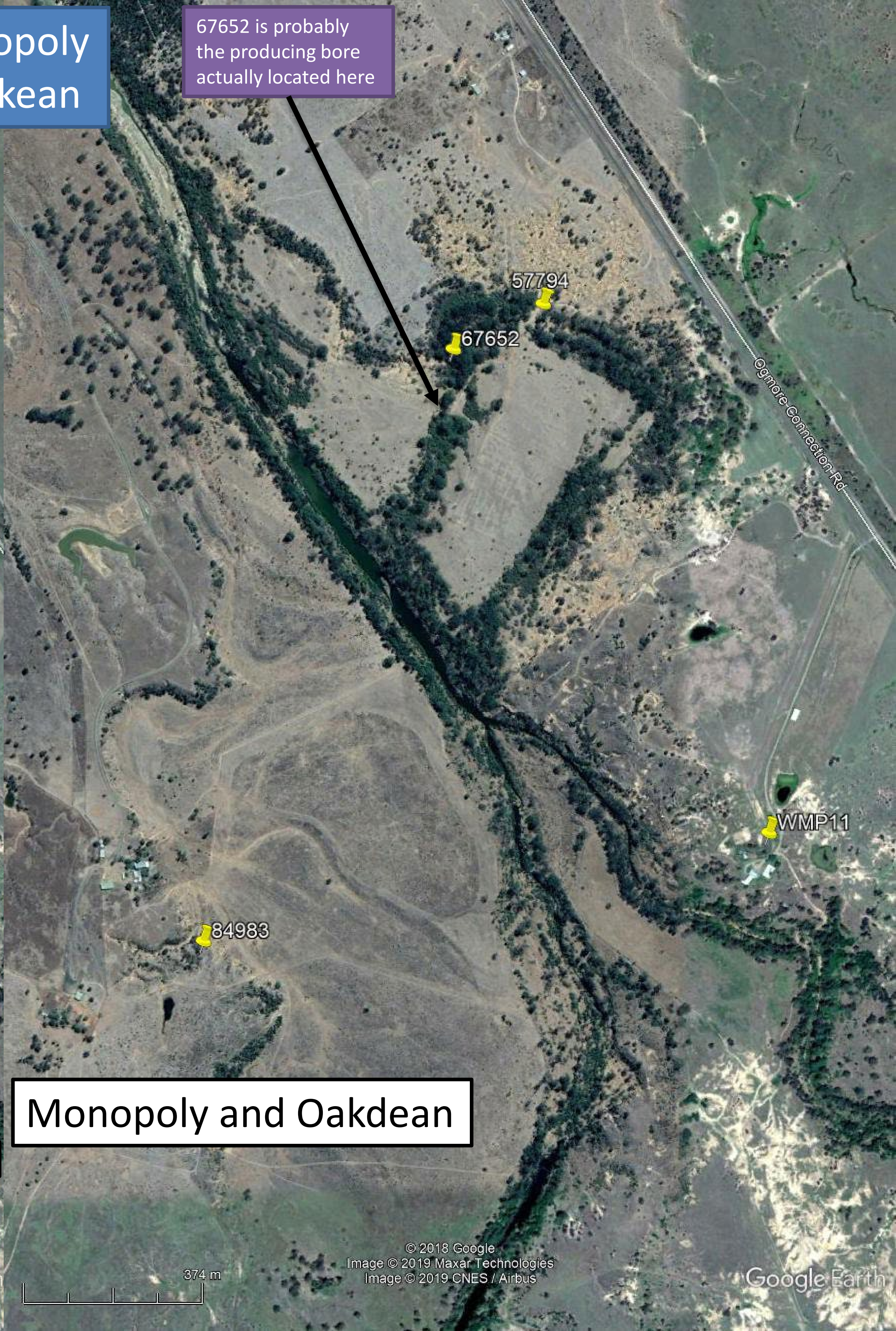
At around 45m deep the resistivity dataset is almost pervasively extremely conductive. A response such as this is suspected to be an artefact however moving AgTEM away to another site eliminated further detection of this feature – showing that it is genuinely present at the Ogmore site but seems to be strongly overemphasized. Real explanations of such a layer include pervasive coked coal (thought to be impossible at this site) or higher salinity in a layer. It is probable that this real conductive layer modelled at 45m may be strongly enhanced and depth-distorted due to modelling imperfection but appears to be otherwise present.

Modelled Resistivity @ 60m deep

Monopoly & Oakean



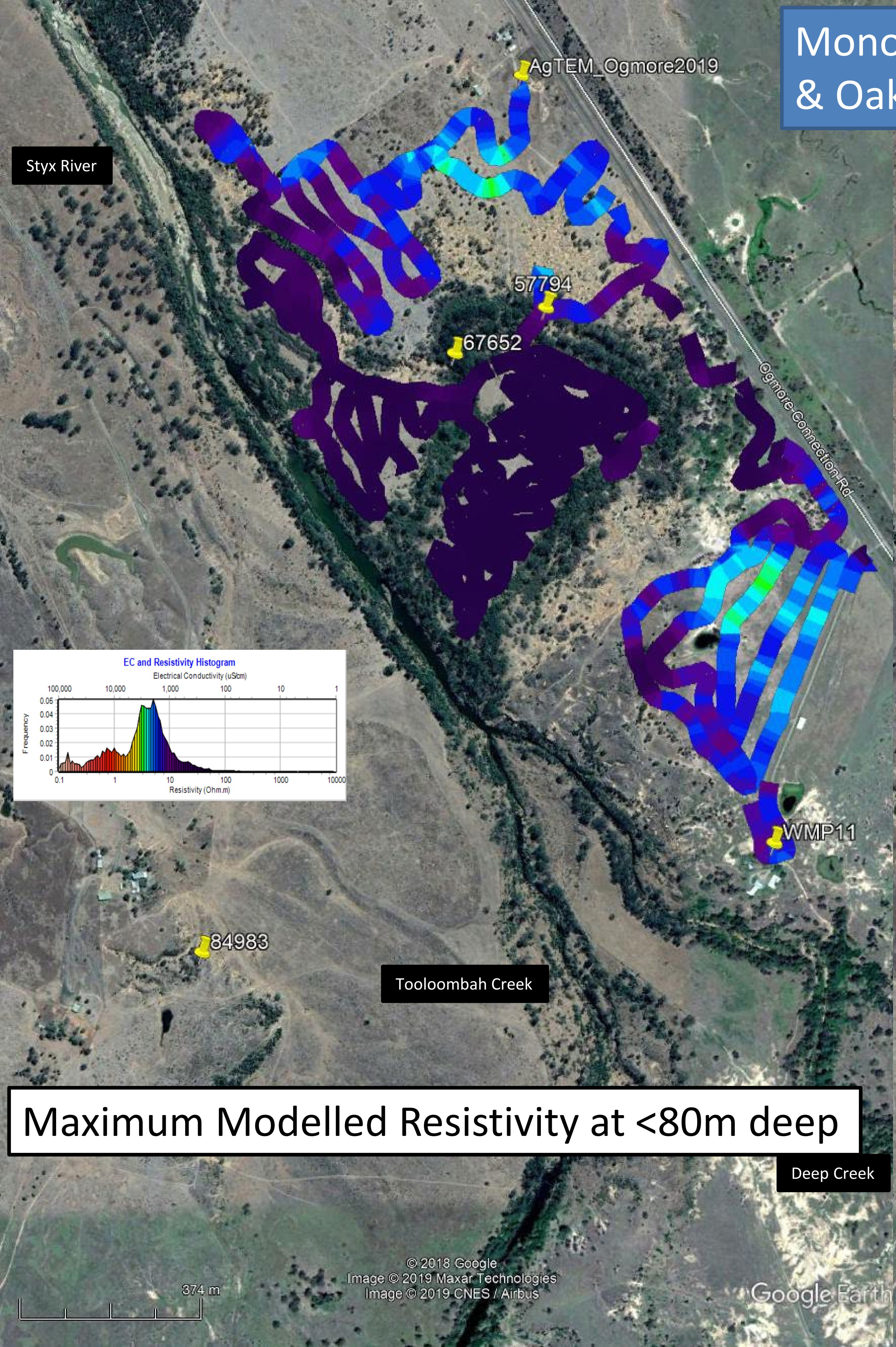
Modelled Resistivity @ 80m deep



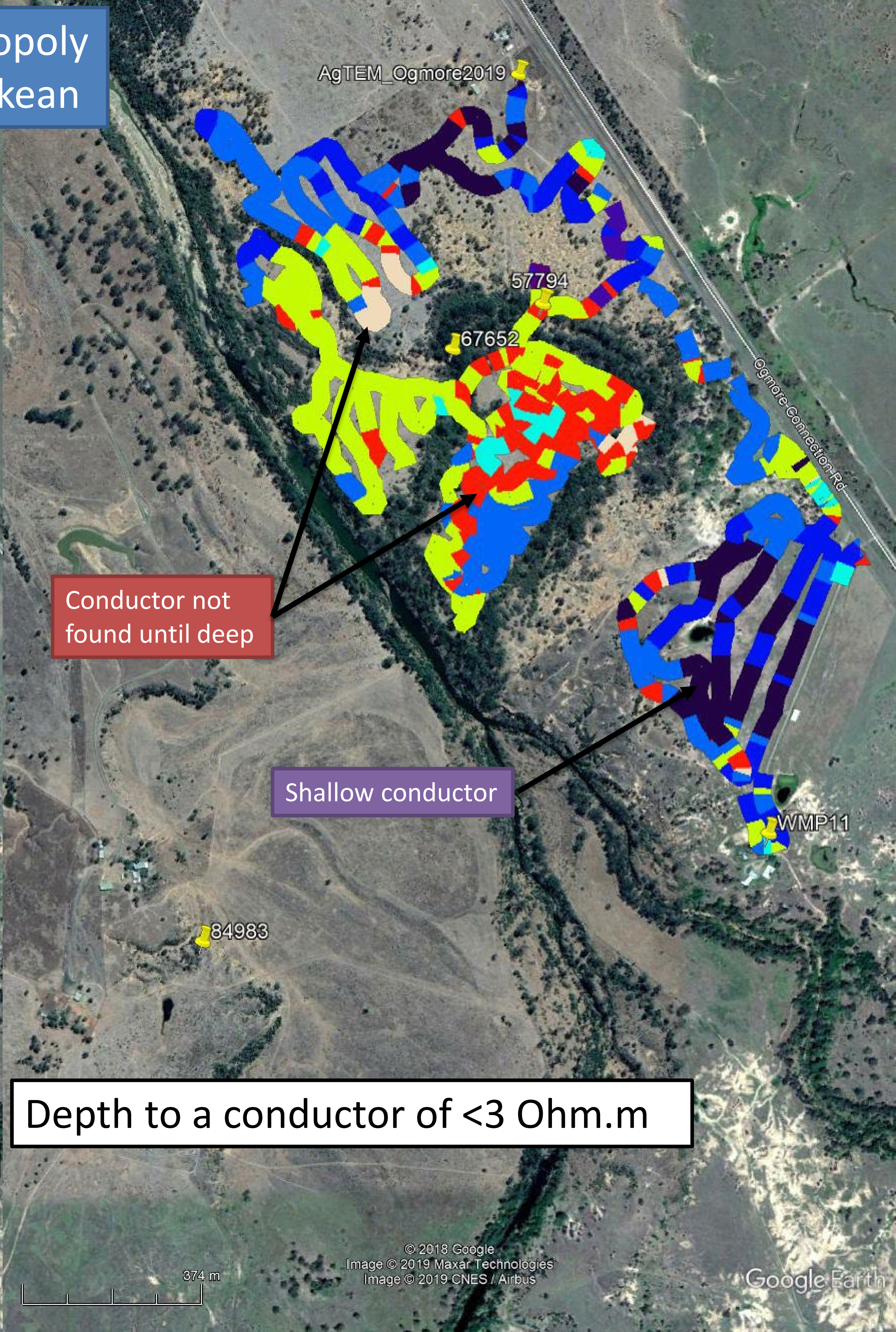
67652 is probably the producing bore actually located here

Monopoly and Oakdean

Monopoly & Oakean



Maximum Modelled Resistivity at <80m deep

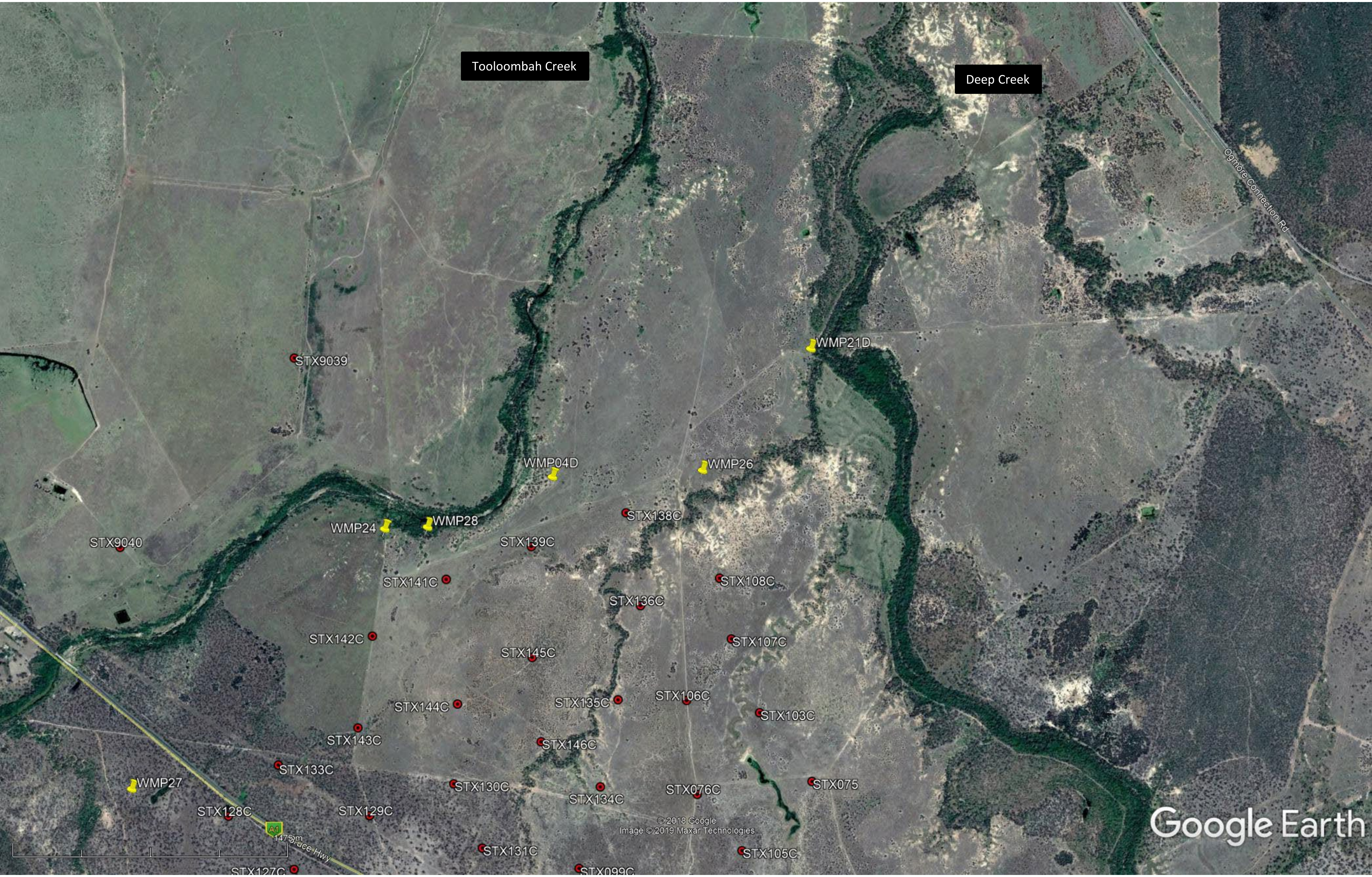


Conductor not found until deep

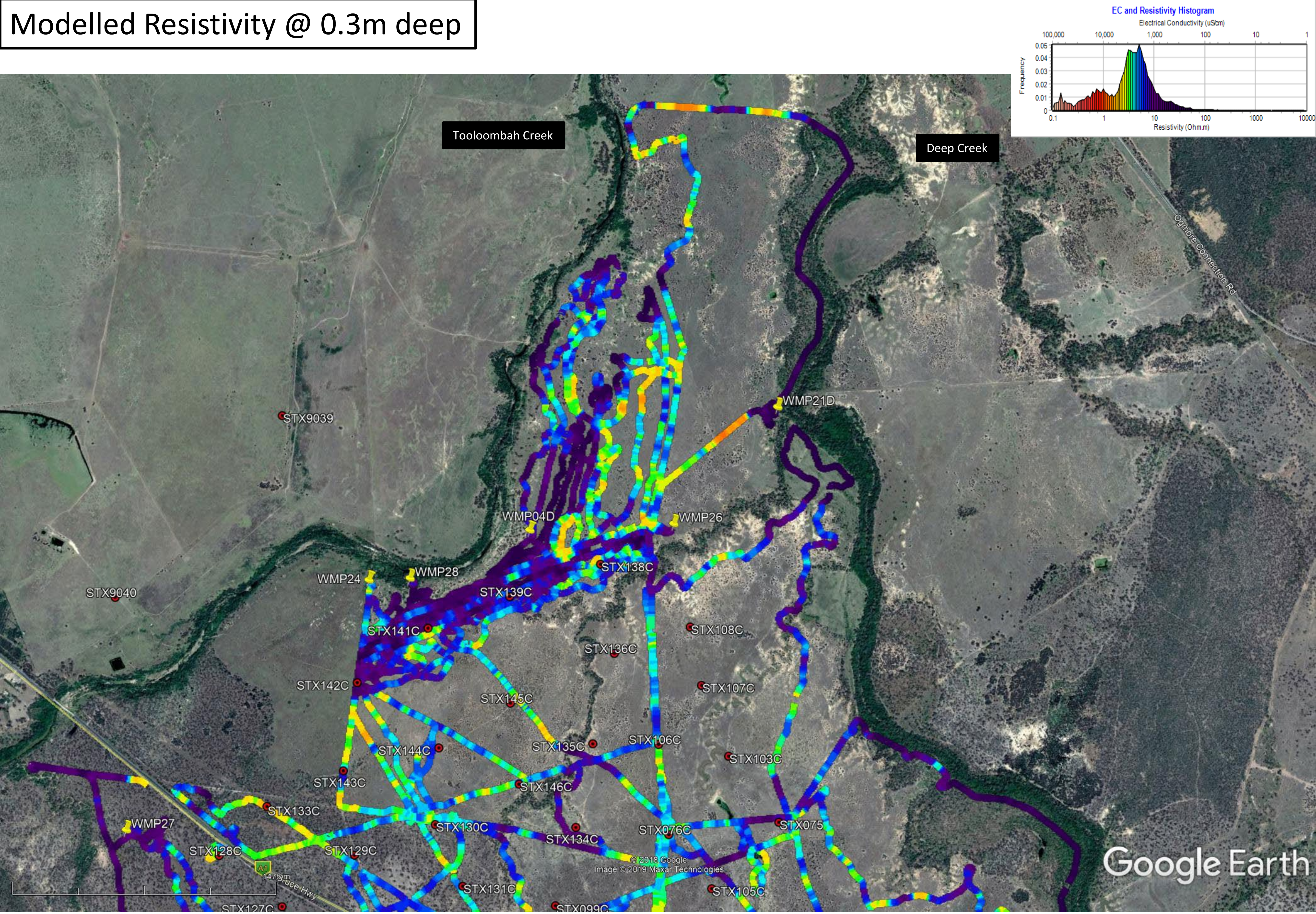
Shallow conductor

Depth to a conductor of <3 Ohm.m

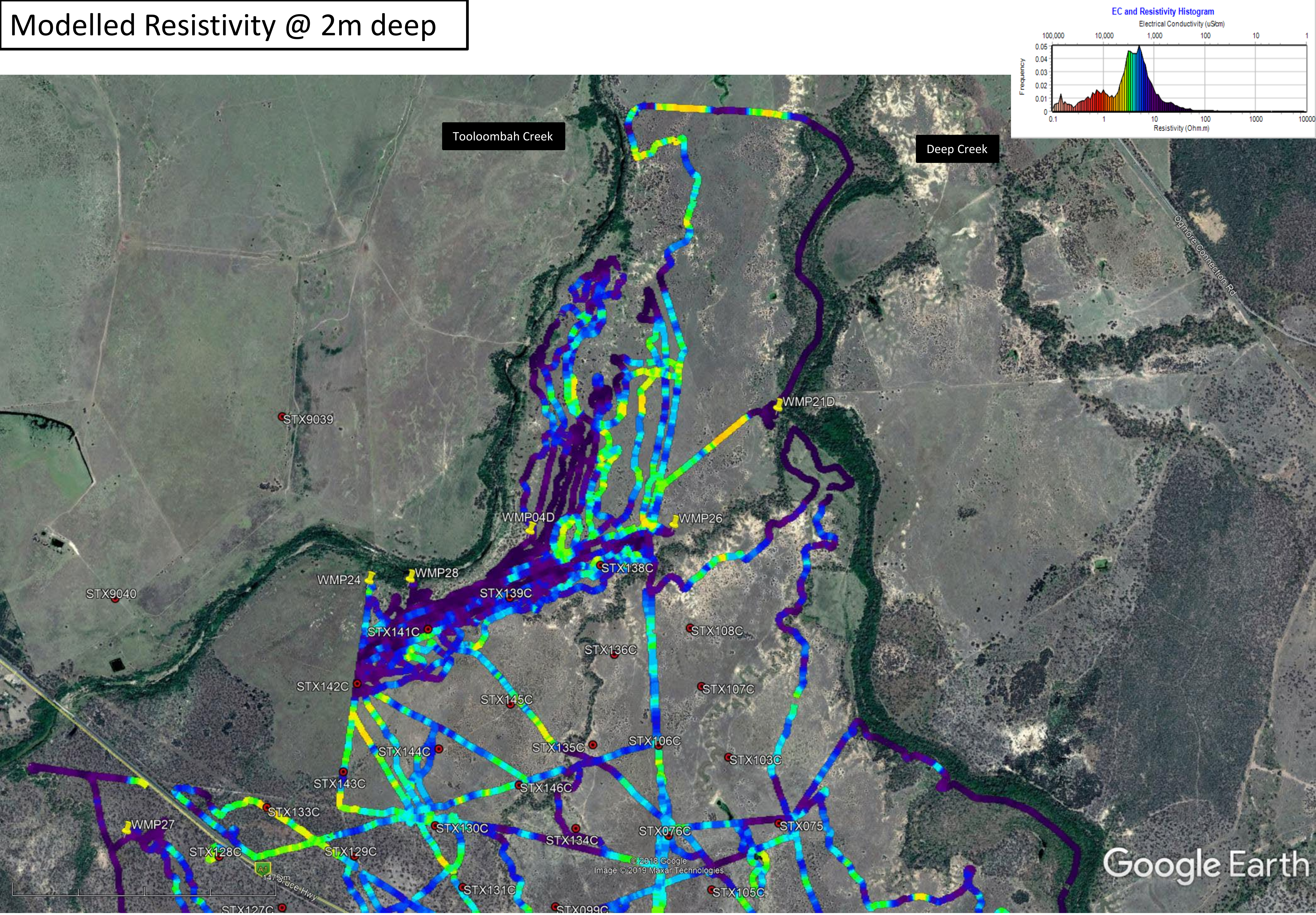
Mamelon North and Bar-H Background Image



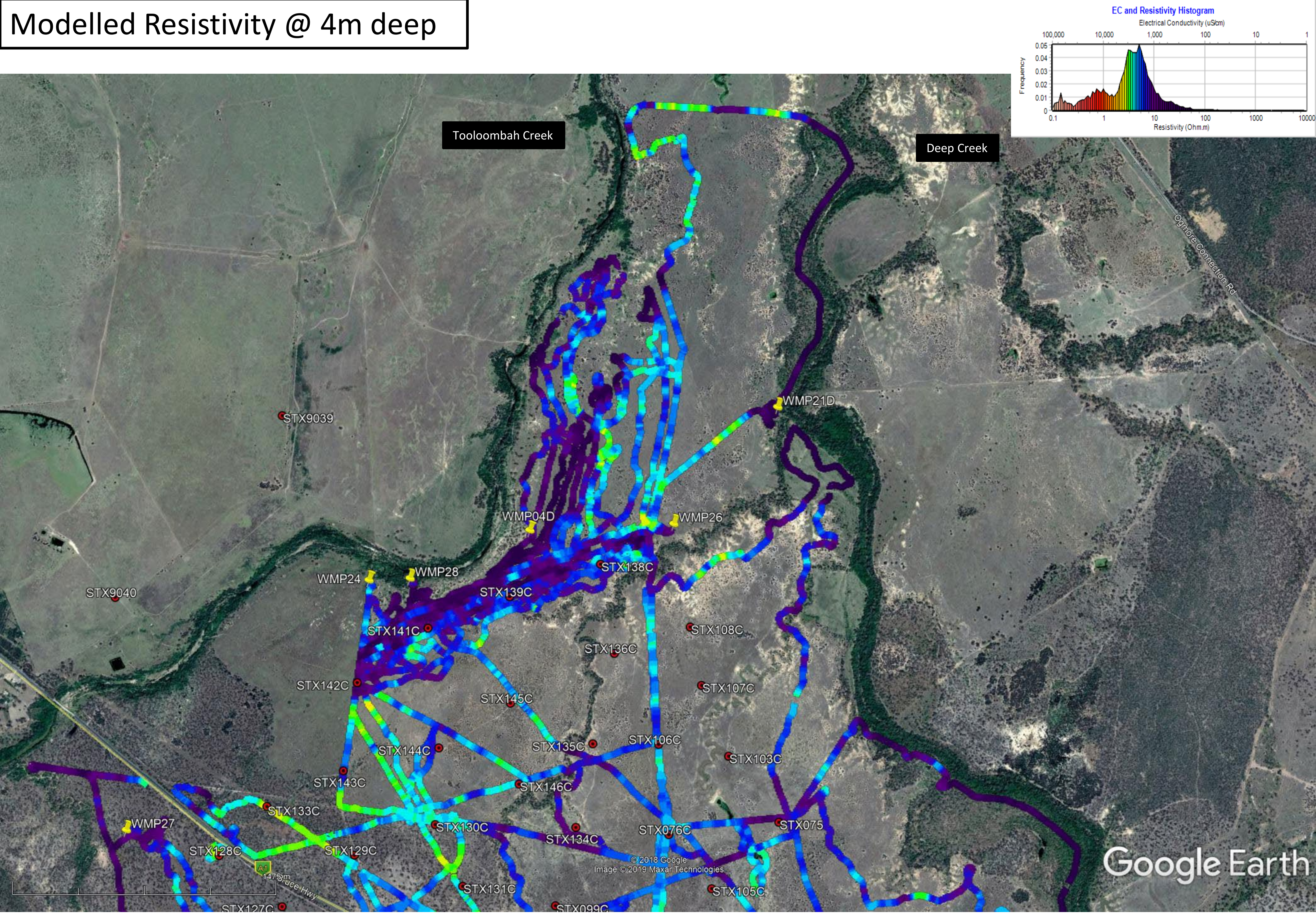
Modelled Resistivity @ 0.3m deep



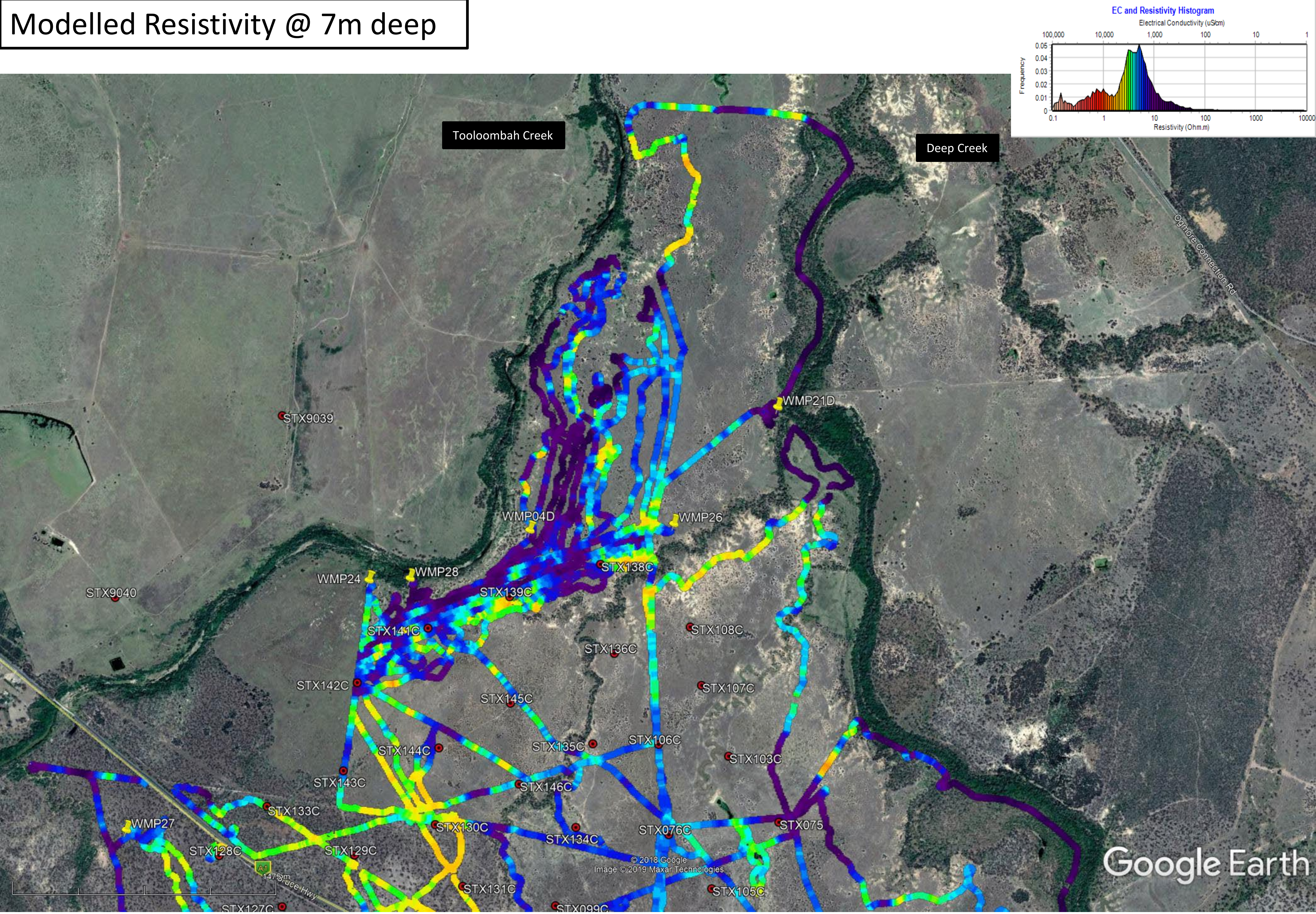
Modelled Resistivity @ 2m deep



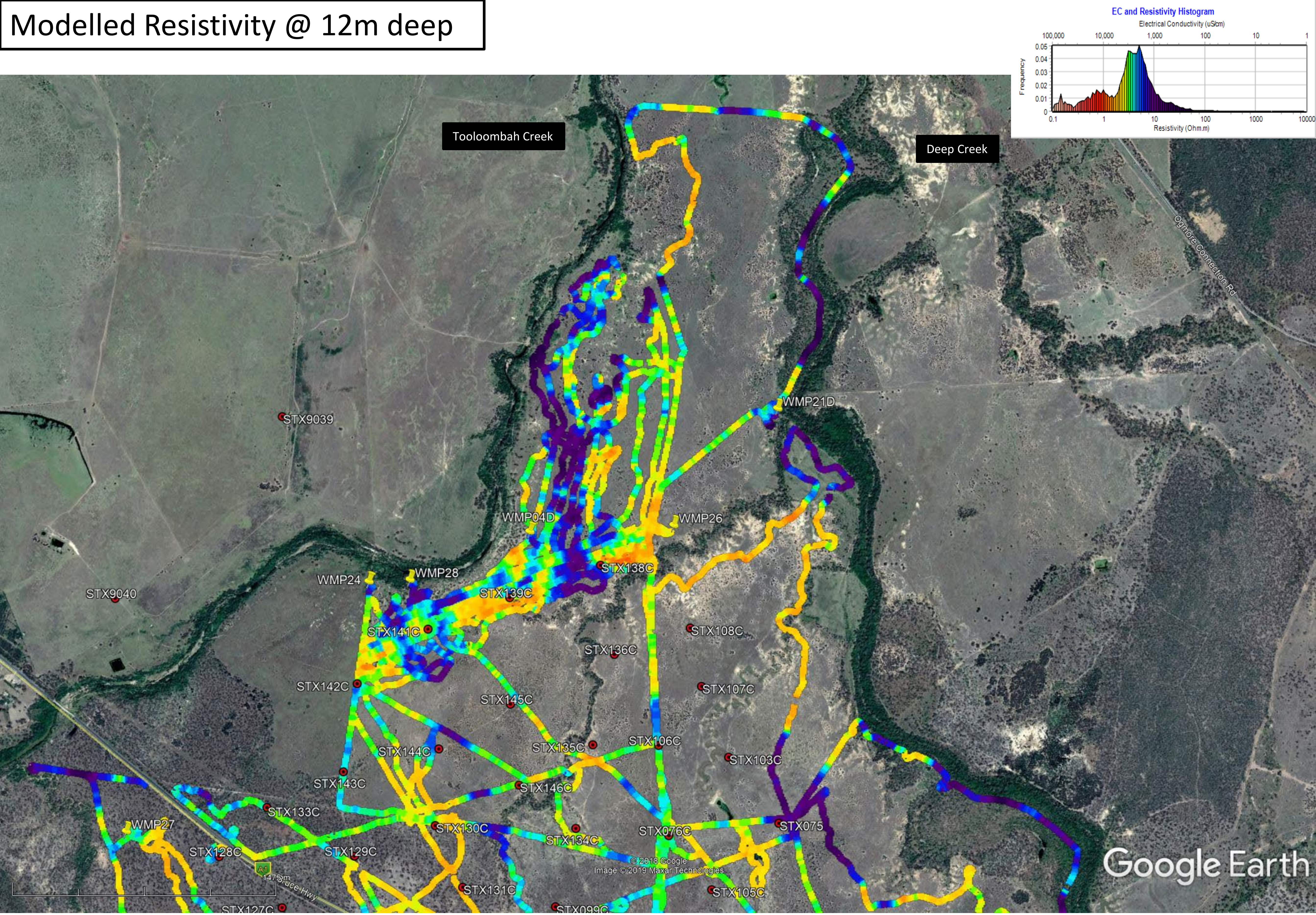
Modelled Resistivity @ 4m deep



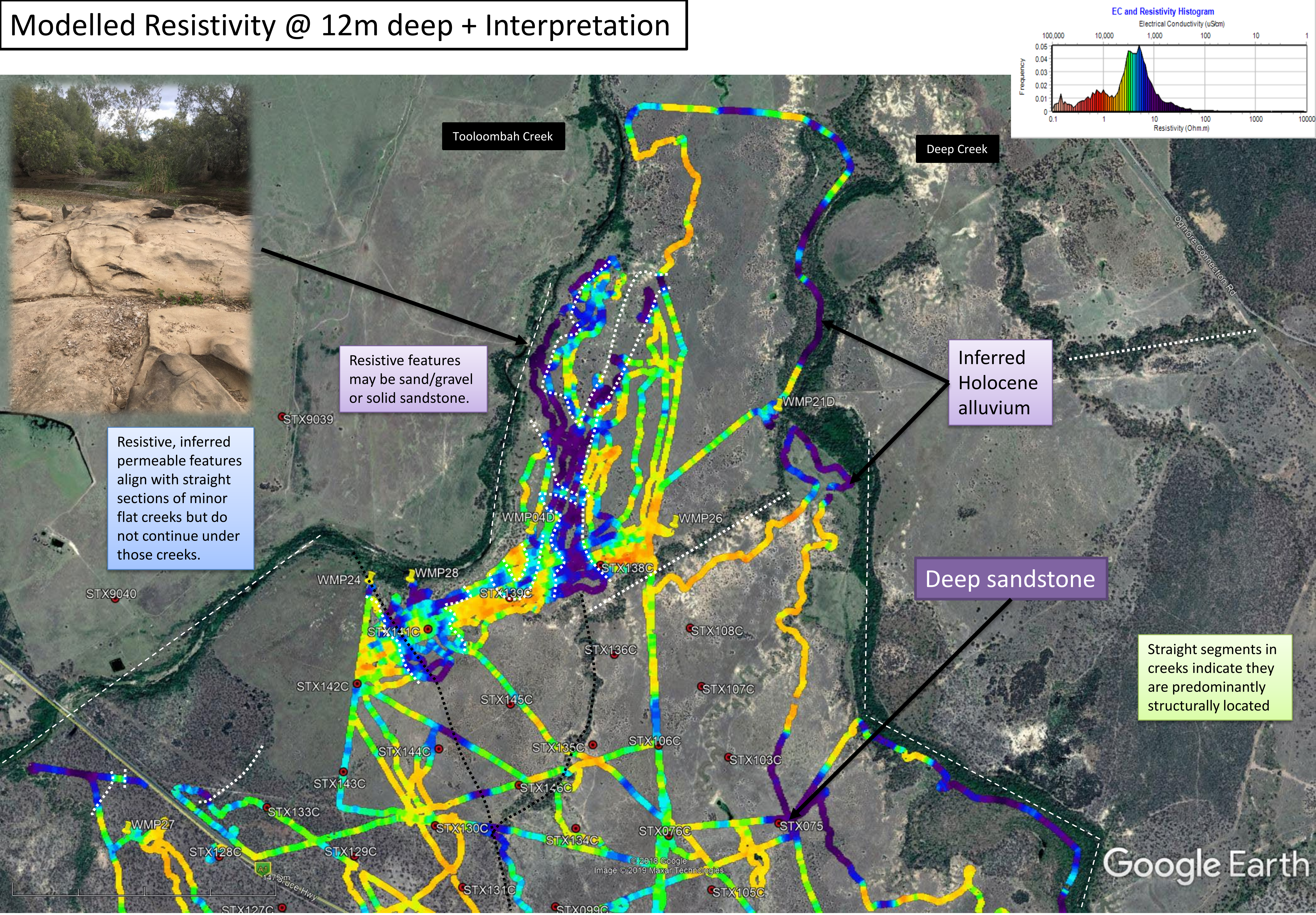
Modelled Resistivity @ 7m deep



Modelled Resistivity @ 12m deep



Modelled Resistivity @ 12m deep + Interpretation



Resistive features may be sand/gravel or solid sandstone.

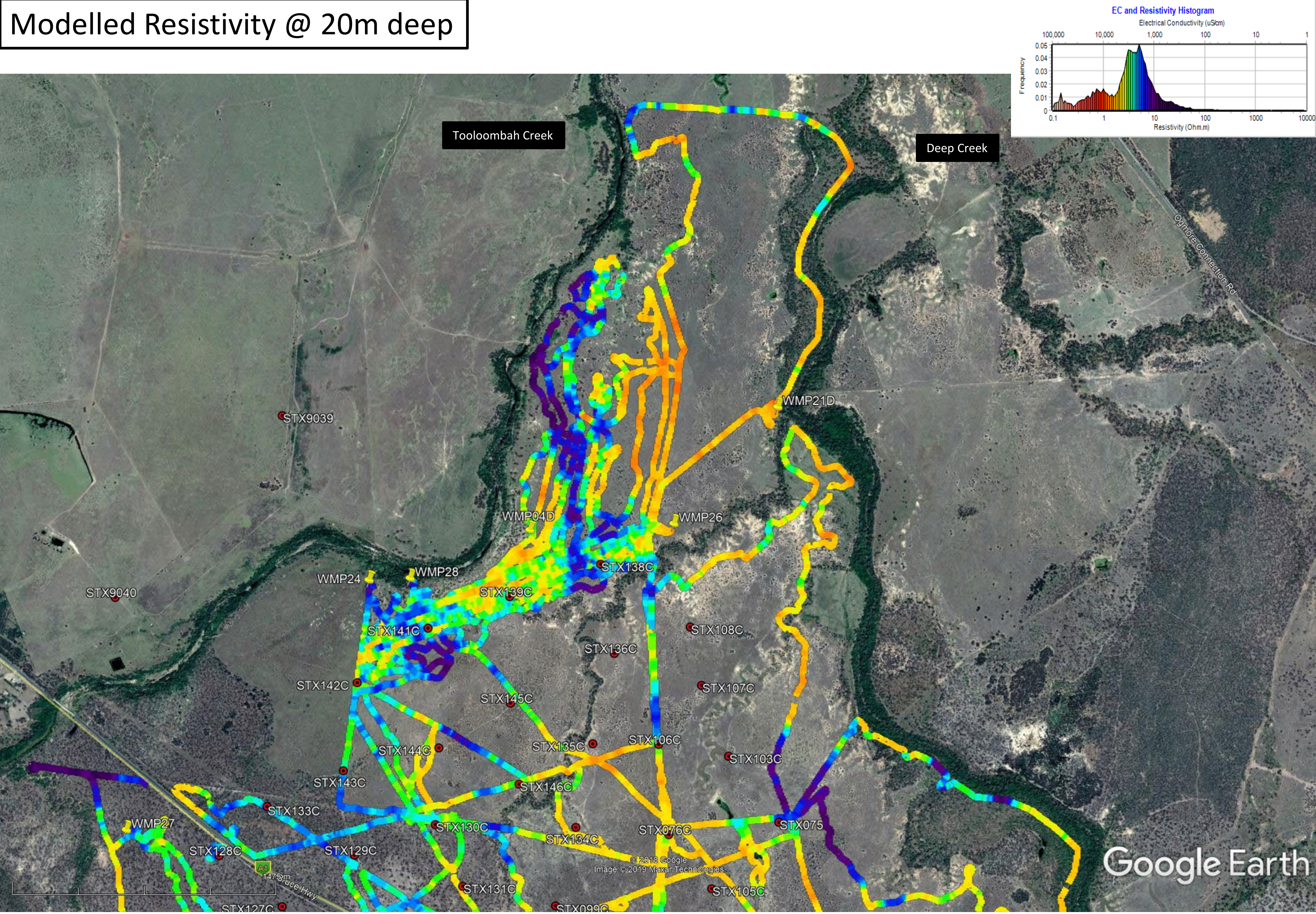
Resistive, inferred permeable features align with straight sections of minor flat creeks but do not continue under those creeks.

Inferred Holocene alluvium

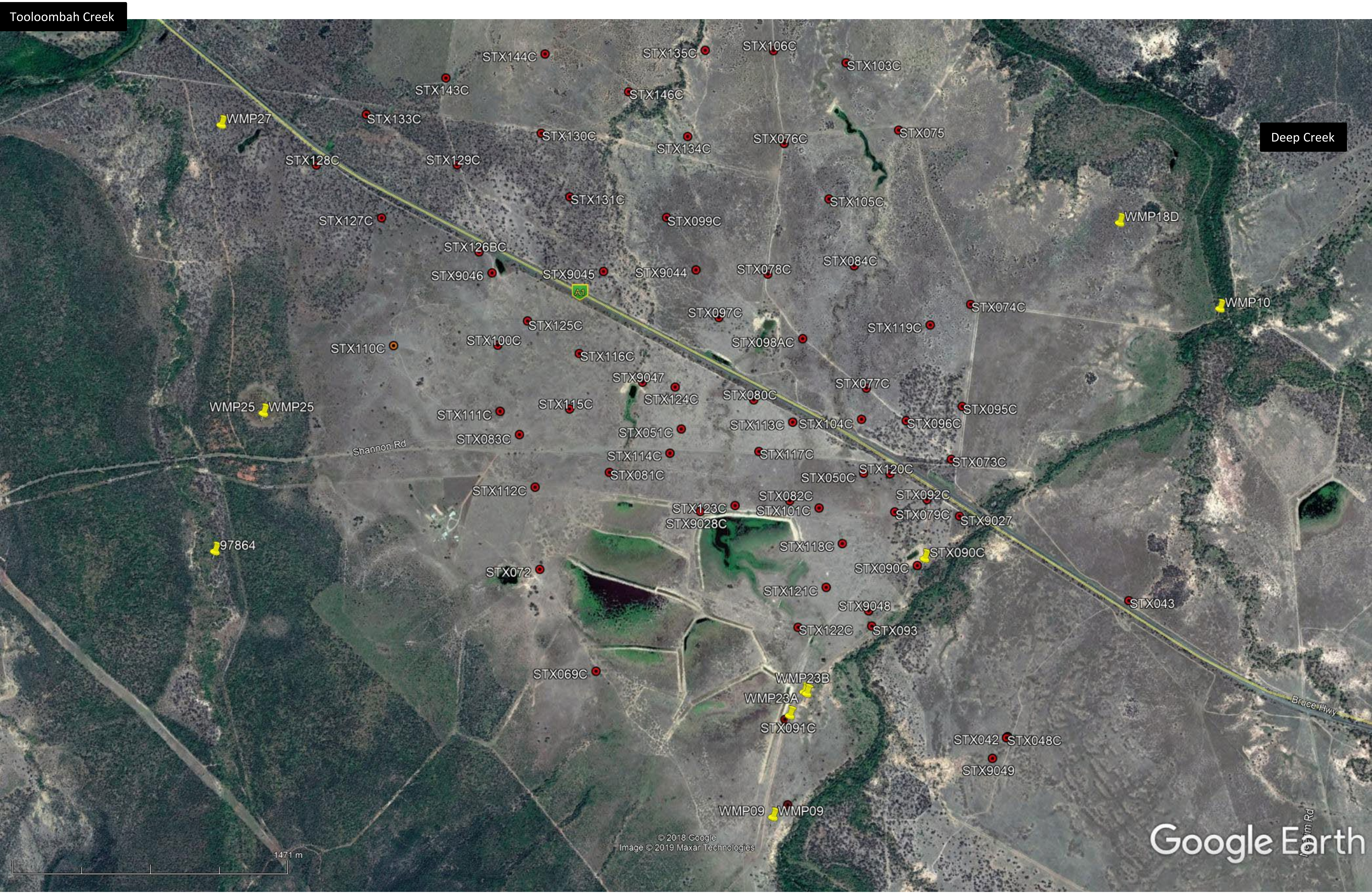
Deep sandstone

Straight segments in creeks indicate they are predominantly structurally located

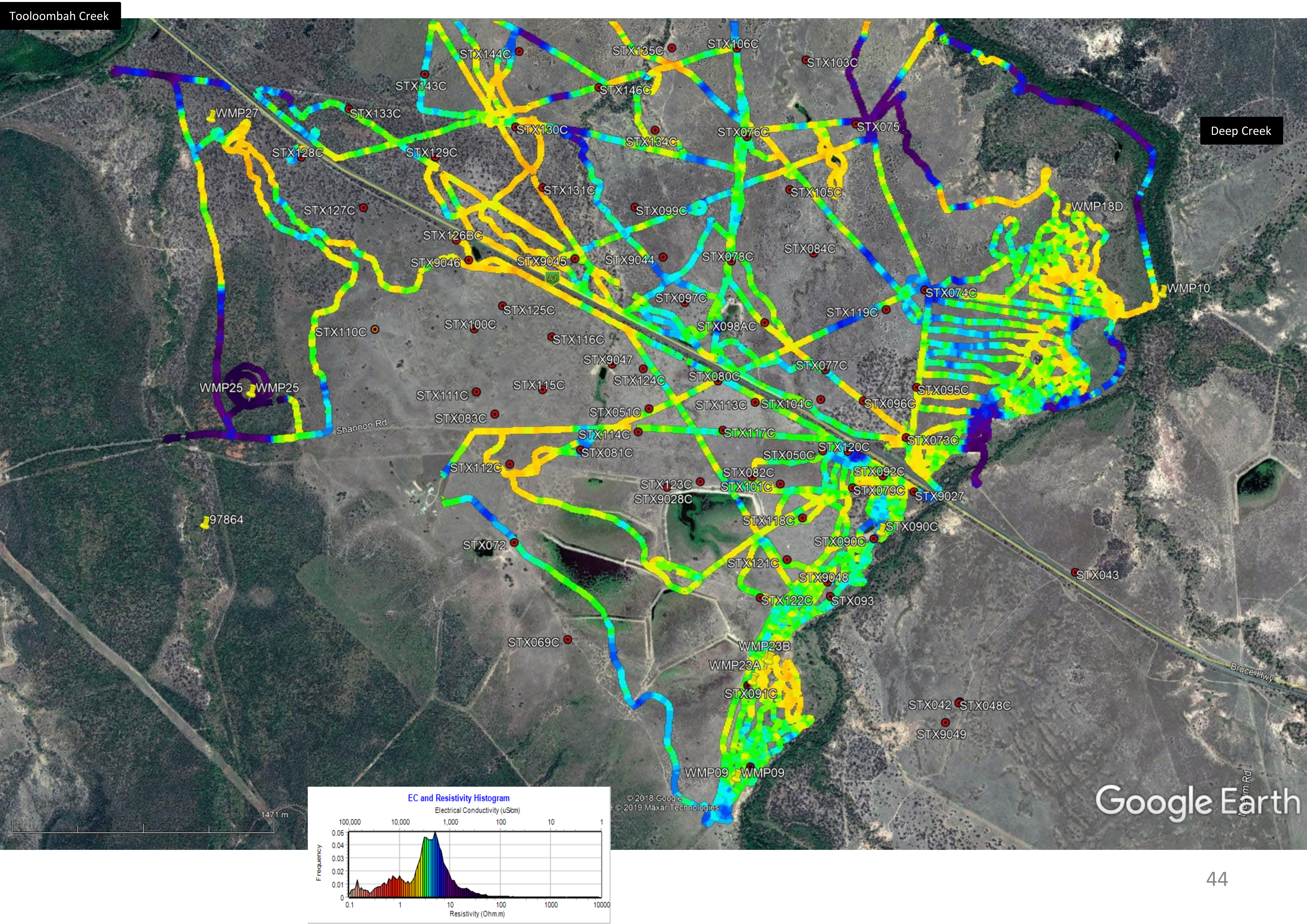
Modelled Resistivity @ 20m deep



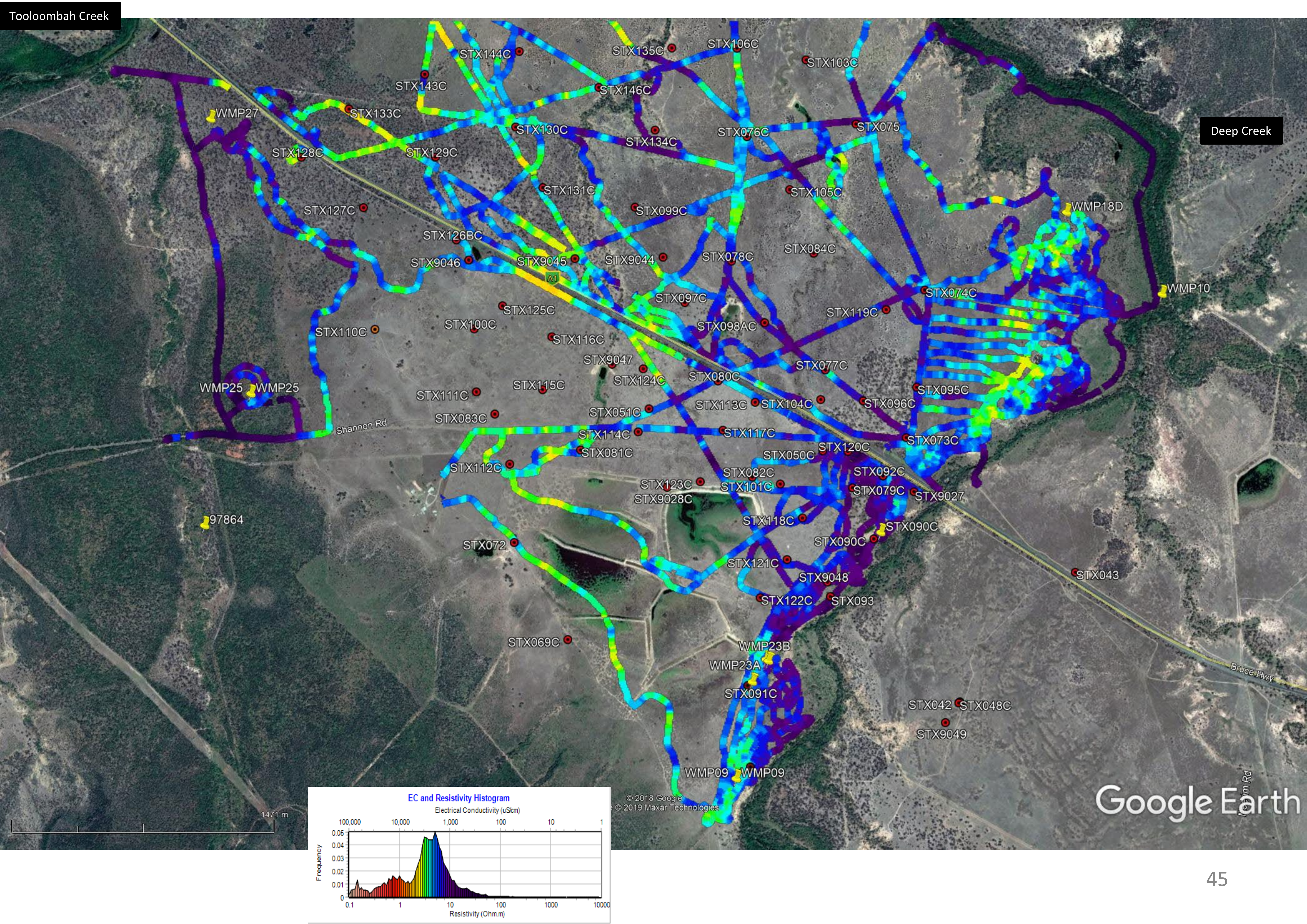
Mamelon South and Brussels Background Image



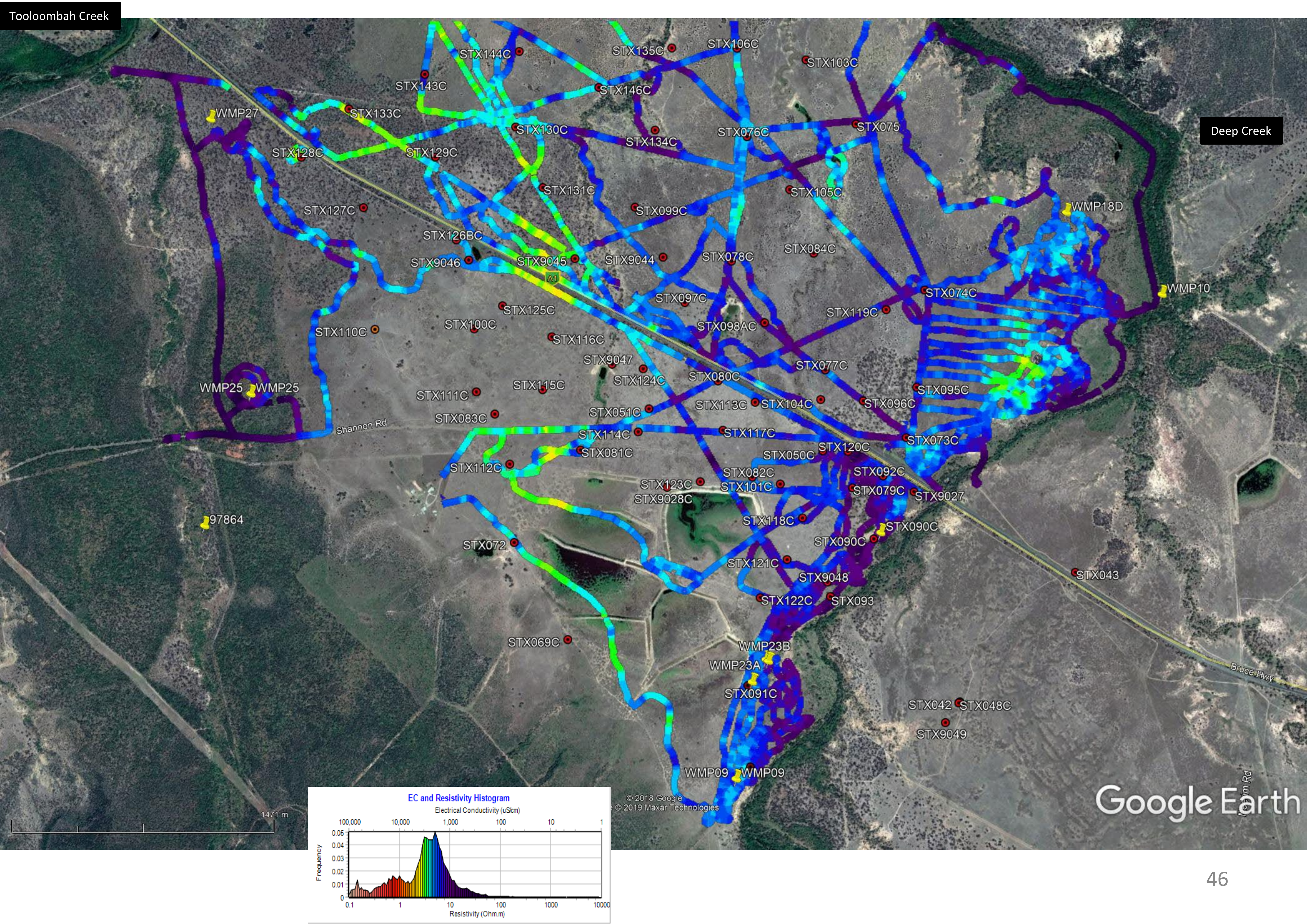
Modelled Resistivity @ 0.3m deep



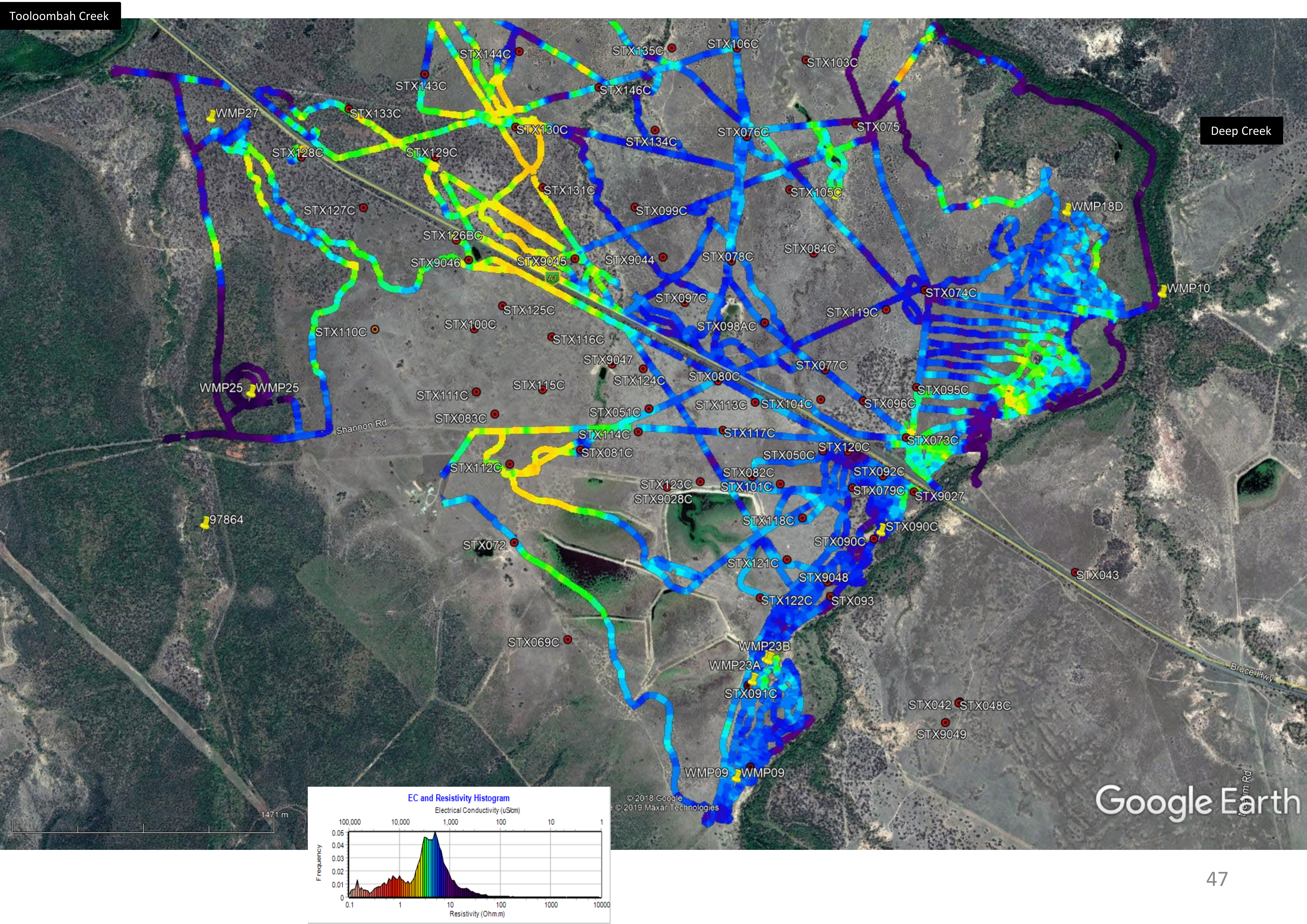
Modelled Resistivity @ 2m deep



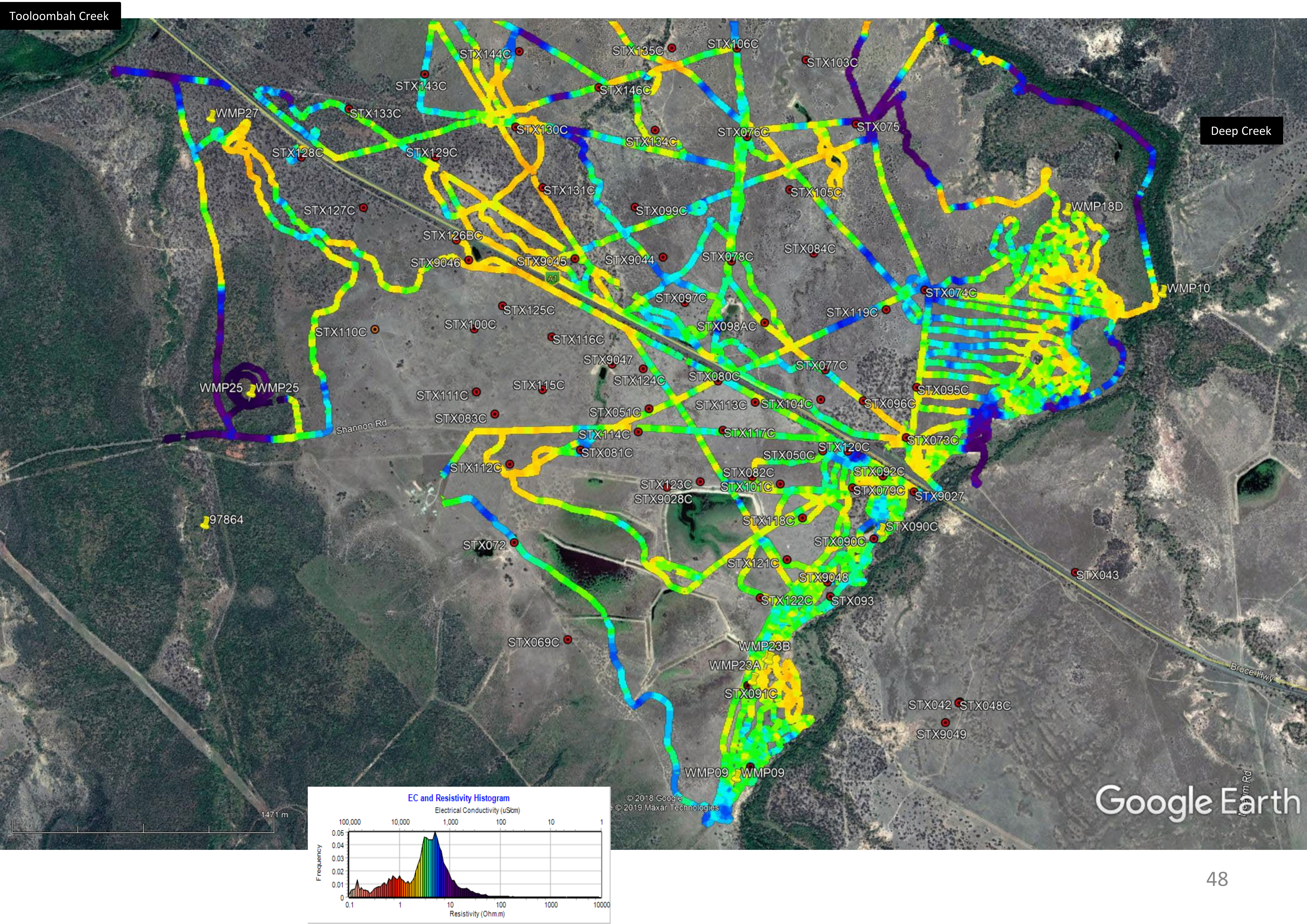
Modelled Resistivity @ 4m deep



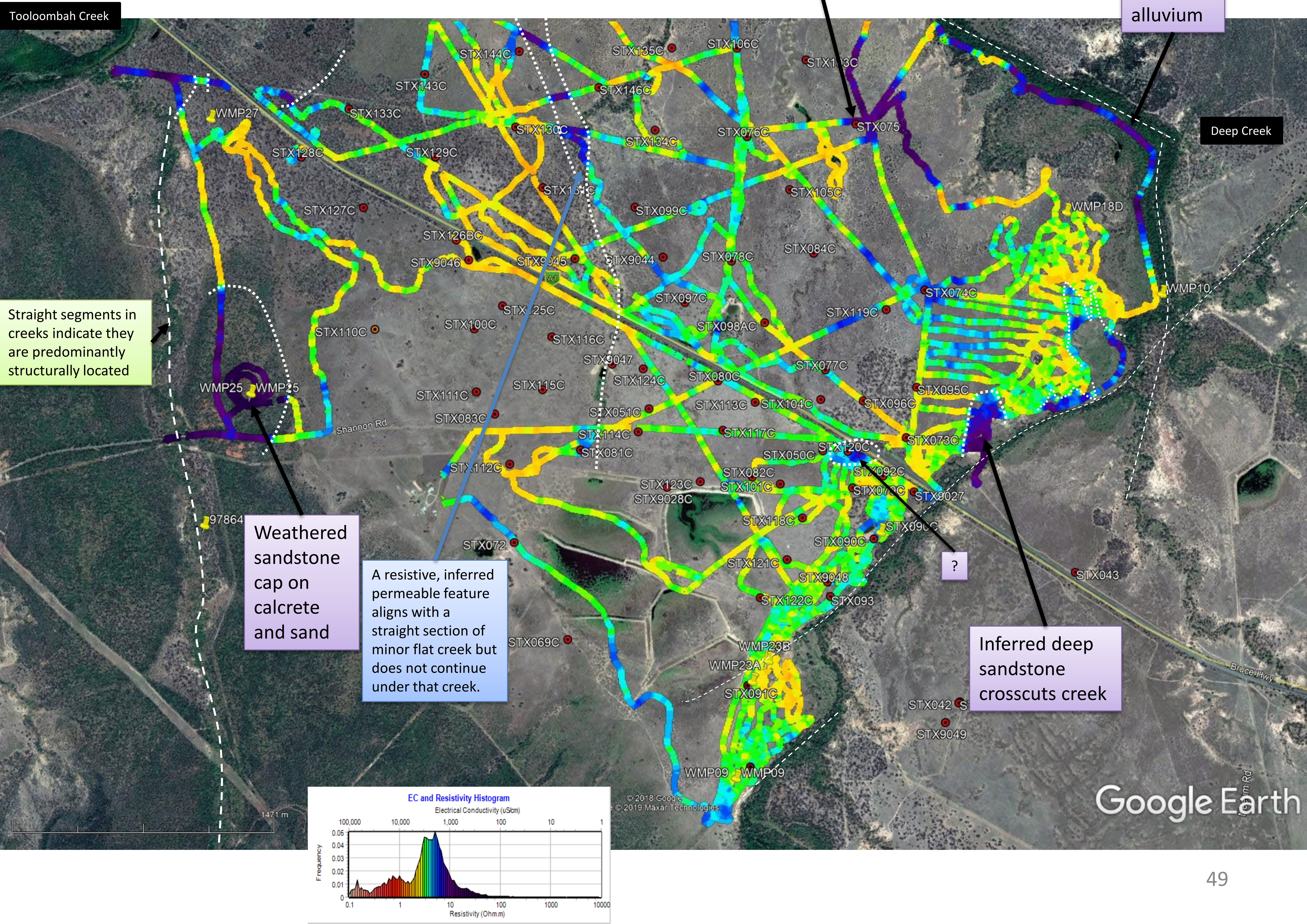
Modelled Resistivity @ 7m deep



Modelled Resistivity @ 12m deep



Modelled Resistivity @ 12m deep + Interpretation



Deep sandstone

Inferred Holocene alluvium

Straight segments in creeks indicate they are predominantly structurally located

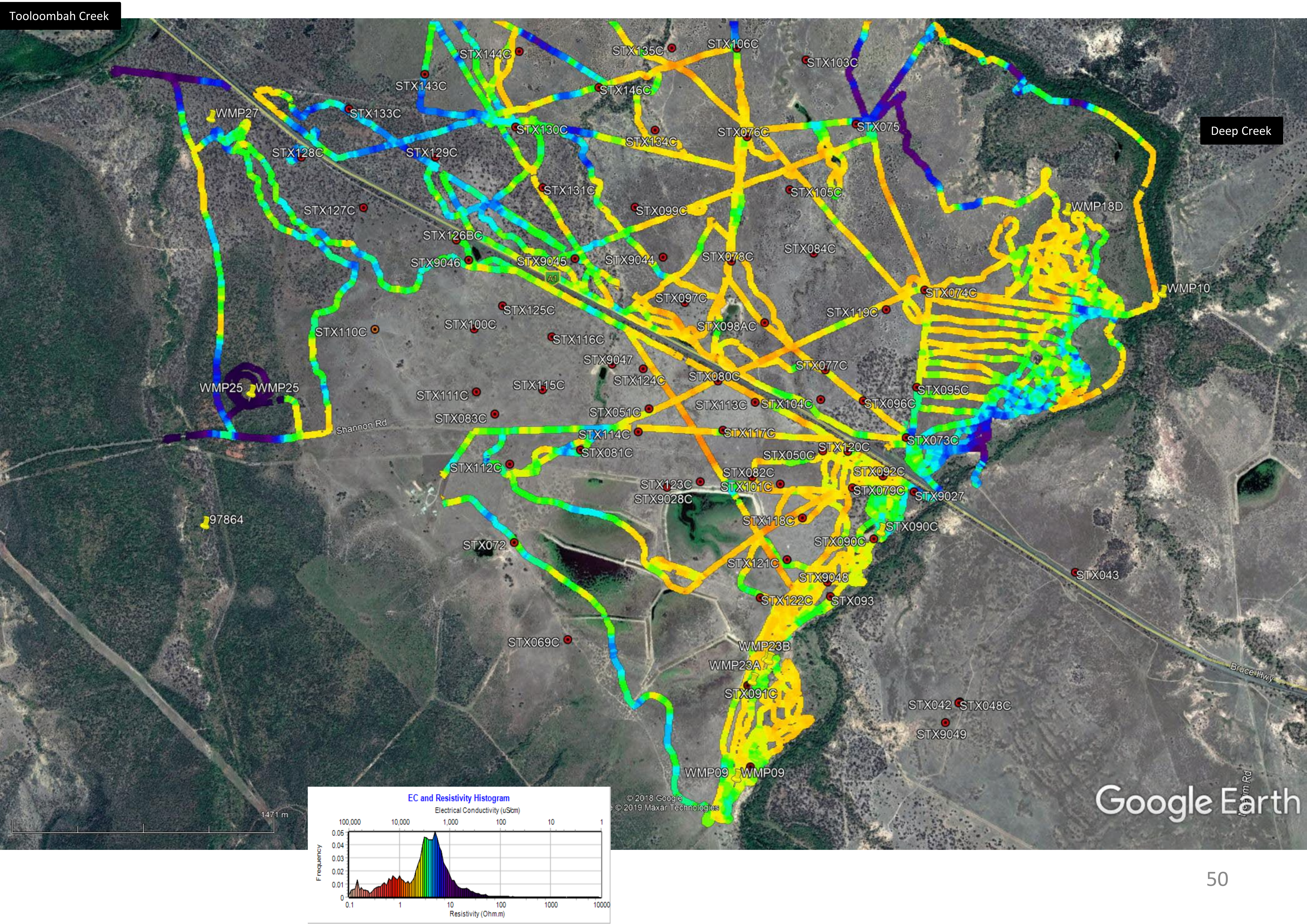
Weathered sandstone cap on calcrete and sand

A resistive, inferred permeable feature aligns with a straight section of minor flat creek but does not continue under that creek.

?

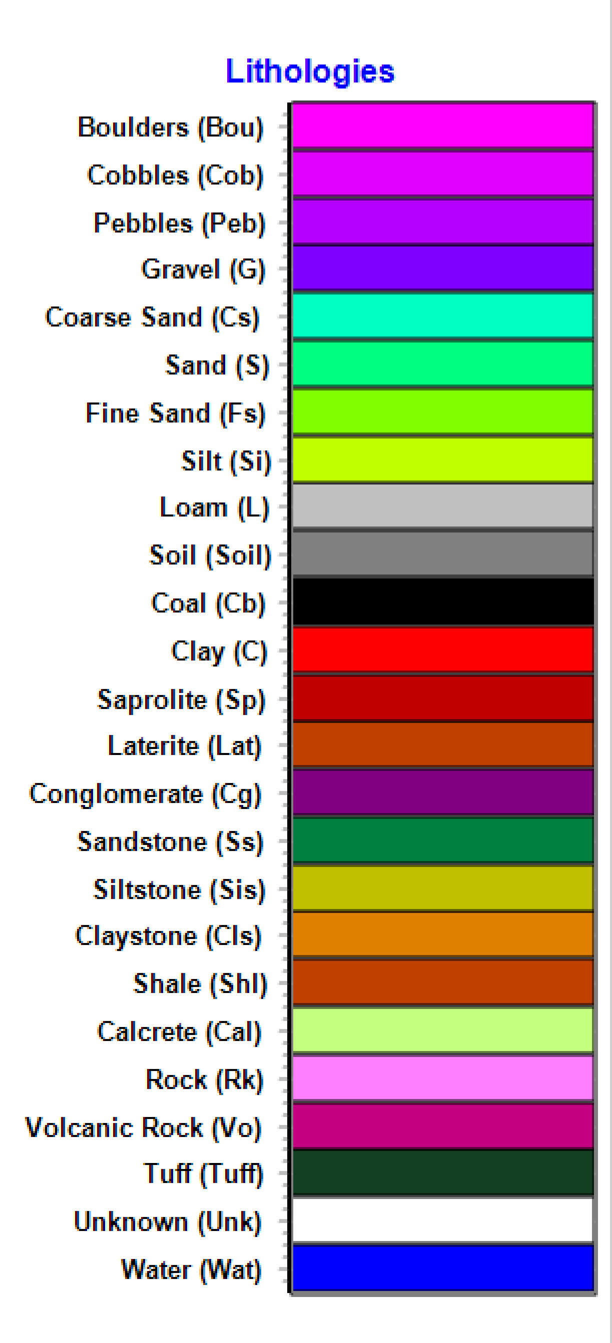
Inferred deep sandstone crosscuts creek

Modelled Resistivity @ 20m deep

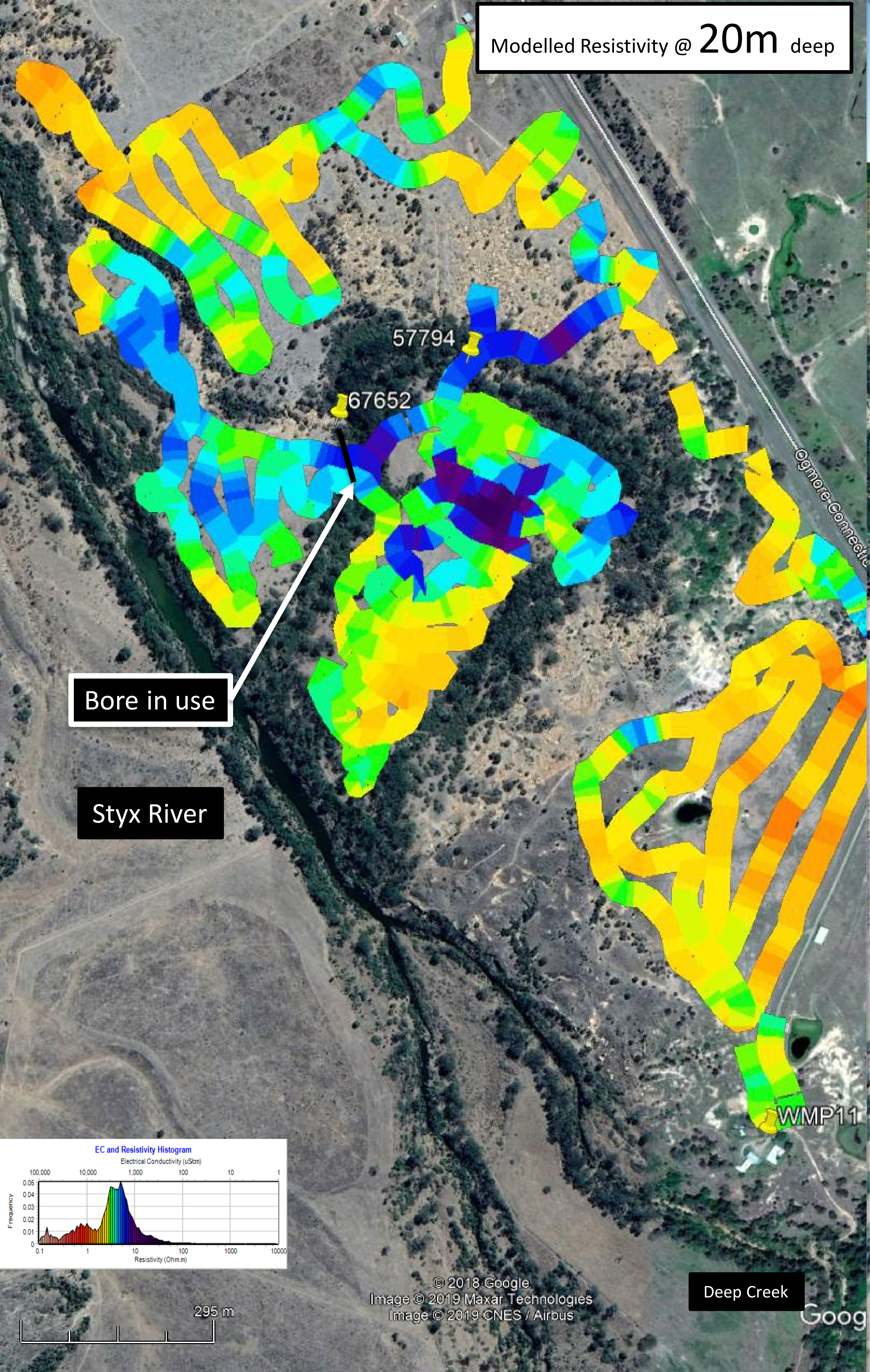


Three dimensional presentation

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

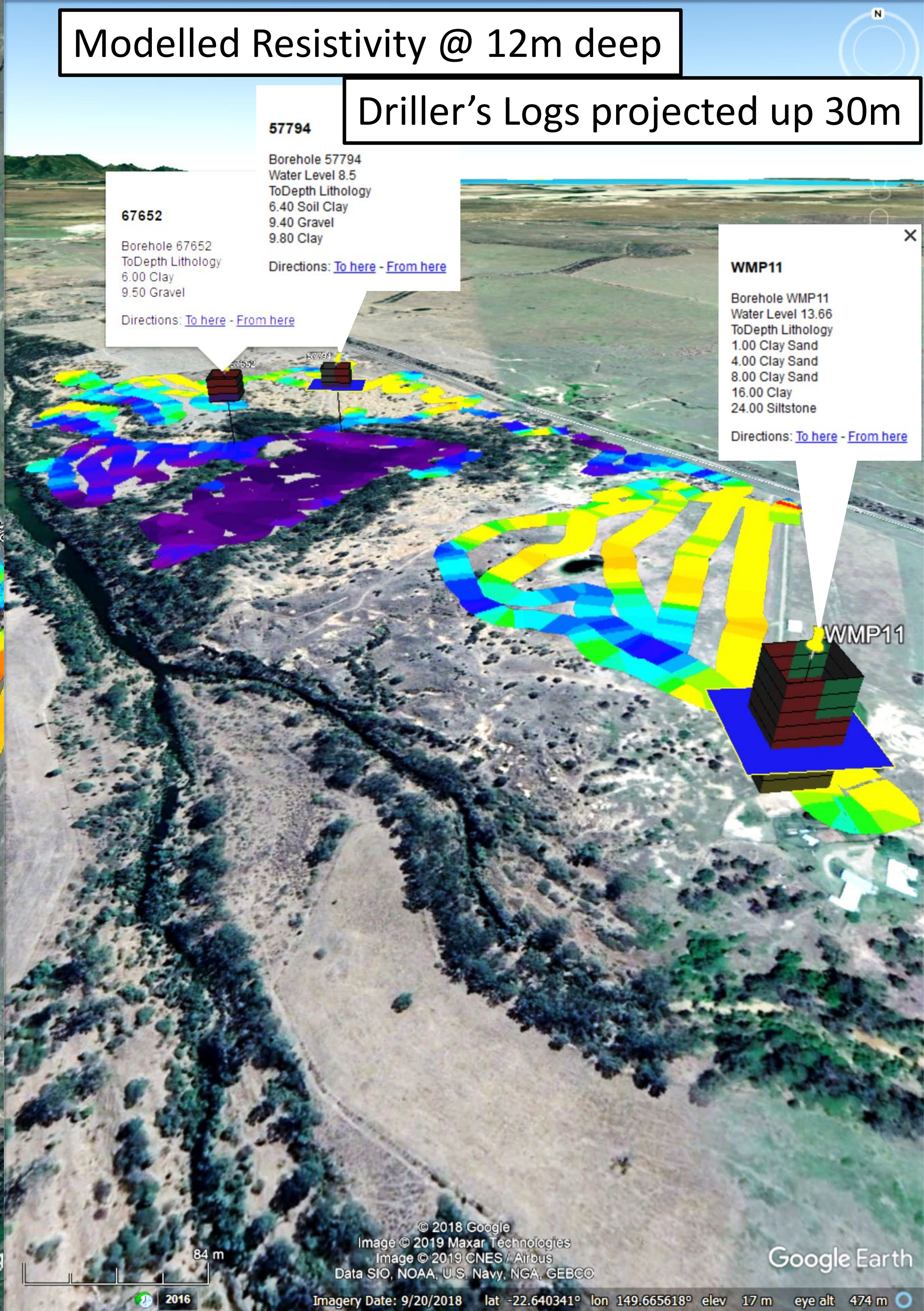


Modelled Resistivity @ 20m deep



Modelled Resistivity @ 12m deep

Driller's Logs projected up 30m



57794

Borehole 57794
Water Level 8.5
ToDepth Lithology
6.40 Soil Clay
9.40 Gravel
9.80 Clay

Directions: To here - From here

67652

Borehole 67652
ToDepth Lithology
6.00 Clay
9.50 Gravel

Directions: To here - From here

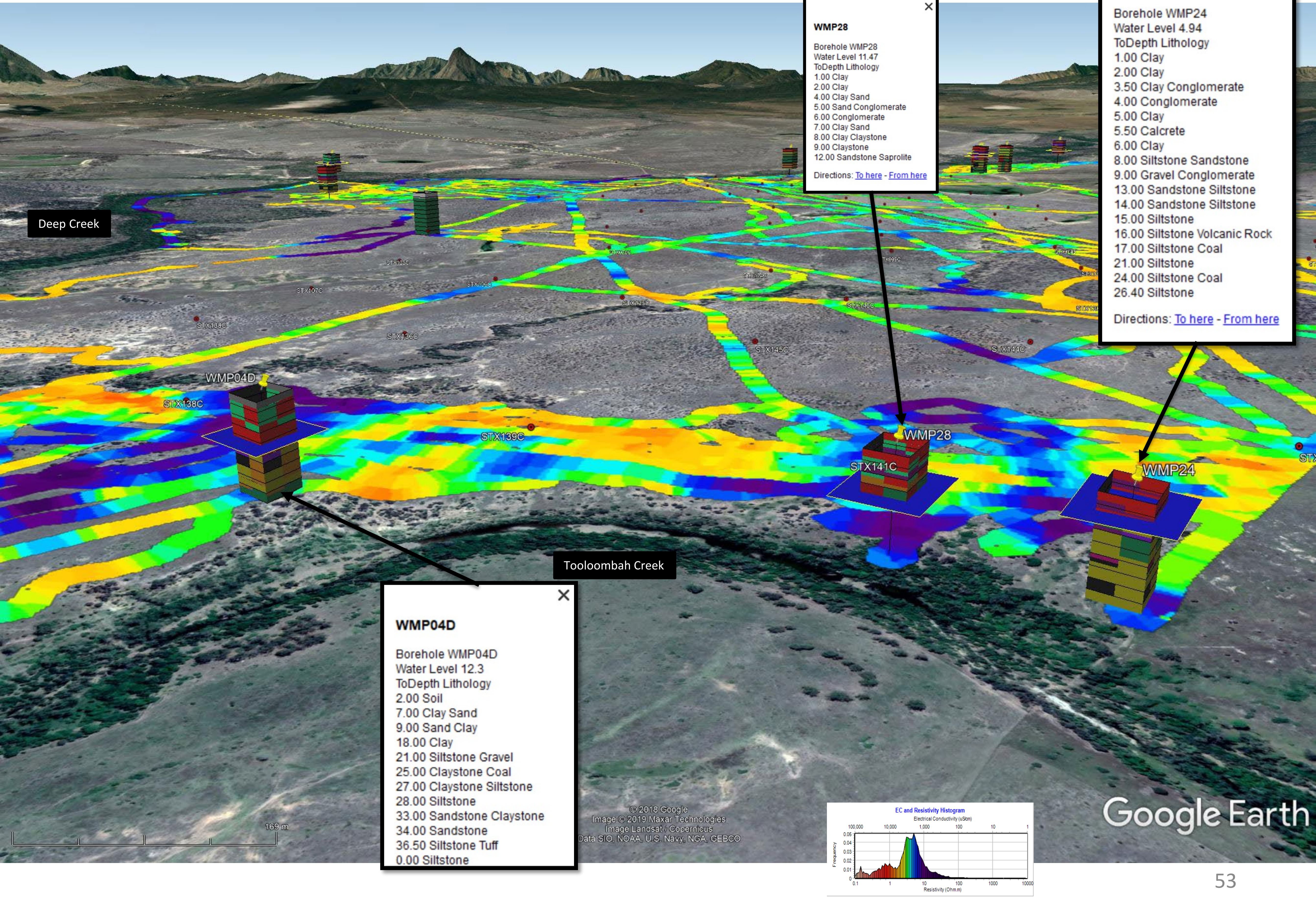
WMP11

Borehole WMP11
Water Level 13.66
ToDepth Lithology
1.00 Clay Sand
4.00 Clay Sand
8.00 Clay Sand
16.00 Clay
24.00 Siltstone

Directions: To here - From here

Modelled Resistivity @ 12m deep

Driller's Logs projected up 30m



WMP28

Borehole WMP28
Water Level 11.47
ToDepth Lithology
1.00 Clay
2.00 Clay
4.00 Clay Sand
5.00 Sand Conglomerate
6.00 Conglomerate
7.00 Clay Sand
8.00 Clay Claystone
9.00 Claystone
12.00 Sandstone Saprolite

Directions: To here - From here

WMP24

Borehole WMP24
Water Level 4.94
ToDepth Lithology
1.00 Clay
2.00 Clay
3.50 Clay Conglomerate
4.00 Conglomerate
5.00 Clay
5.50 Calcrete
6.00 Clay
8.00 Siltstone Sandstone
9.00 Gravel Conglomerate
13.00 Sandstone Siltstone
14.00 Sandstone Siltstone
15.00 Siltstone
16.00 Siltstone Volcanic Rock
17.00 Siltstone Coal
21.00 Siltstone
24.00 Siltstone Coal
26.40 Siltstone

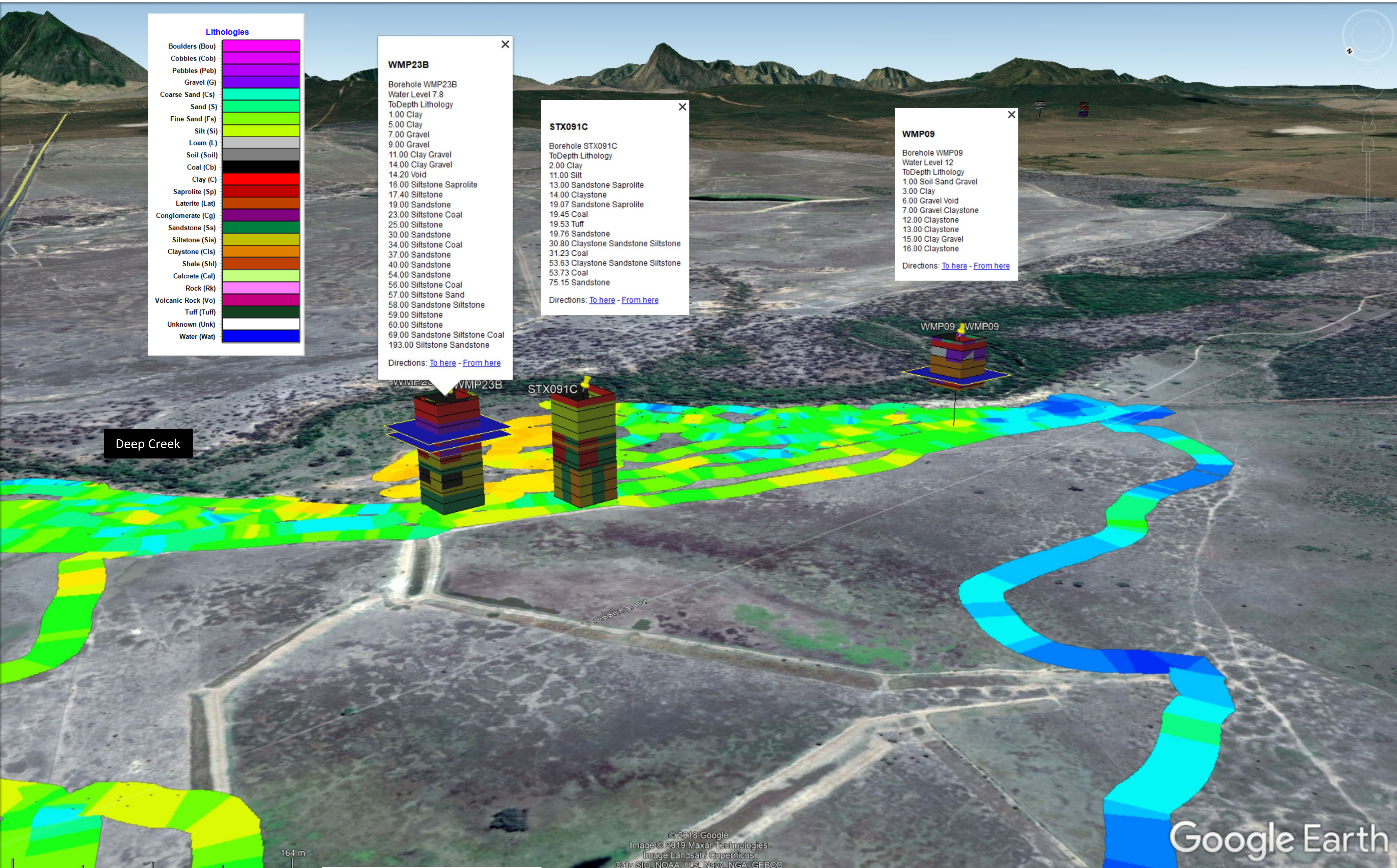
Directions: To here - From here

WMP04D

Borehole WMP04D
Water Level 12.3
ToDepth Lithology
2.00 Soil
7.00 Clay Sand
9.00 Sand Clay
18.00 Clay
21.00 Siltstone Gravel
25.00 Claystone Coal
27.00 Claystone Siltstone
28.00 Siltstone
33.00 Sandstone Claystone
34.00 Sandstone
36.50 Siltstone Tuff
0.00 Siltstone

Modelled Resistivity @ 12m deep

Driller's Logs projected up 30m



WMP23B

Borehole WMP23B
Water Level 7.8
ToDepth Lithology
1.00 Clay
5.00 Clay
7.00 Gravel
9.00 Gravel
11.00 Clay Gravel
14.00 Clay Gravel
14.20 Void
16.00 Siltstone Saprolite
17.40 Siltstone
19.00 Sandstone
23.00 Siltstone Coal
25.00 Siltstone
30.00 Sandstone
34.00 Siltstone Coal
37.00 Sandstone
40.00 Sandstone
54.00 Sandstone
56.00 Siltstone Coal
57.00 Siltstone Sand
58.00 Sandstone Siltstone
59.00 Siltstone
60.00 Siltstone
69.00 Sandstone Siltstone Coal
193.00 Siltstone Sandstone

Directions: To here - From here

STX091C

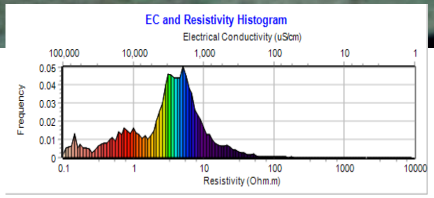
Borehole STX091C
ToDepth Lithology
2.00 Clay
11.00 Silt
13.00 Sandstone Saprolite
14.00 Claystone
19.07 Sandstone Saprolite
19.45 Coal
19.53 Tuff
19.76 Sandstone
30.80 Claystone Sandstone Siltstone
31.23 Coal
53.63 Claystone Sandstone Siltstone
53.73 Coal
75.15 Sandstone

Directions: To here - From here

WMP09

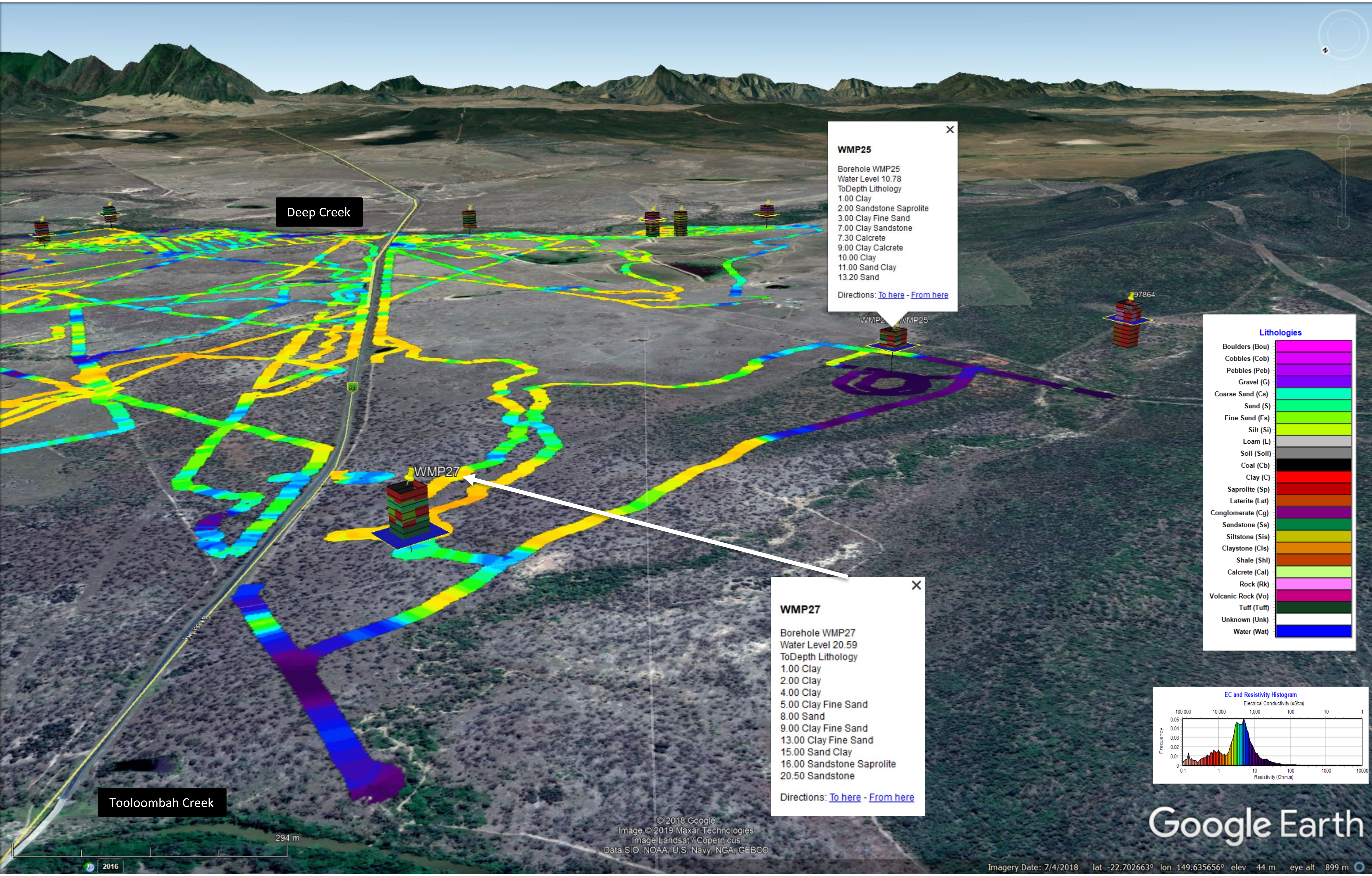
Borehole WMP09
Water Level 12
ToDepth Lithology
1.00 Soil Sand Gravel
3.00 Clay
6.00 Gravel Void
7.00 Gravel Claystone
12.00 Claystone
13.00 Claystone
15.00 Clay Gravel
16.00 Claystone

Directions: To here - From here


EC and Resistivity Histogram

Modelled Resistivity @ 12m deep

Driller's Logs projected up 30m



WMP25

Borehole WMP25
Water Level 10.78
ToDepth Lithology
1.00 Clay
2.00 Sandstone Saprolite
3.00 Clay Fine Sand
7.00 Clay Sandstone
7.30 Calcrete
9.00 Clay Calcrete
10.00 Clay
11.00 Sand Clay
13.20 Sand

Directions: To here - From here

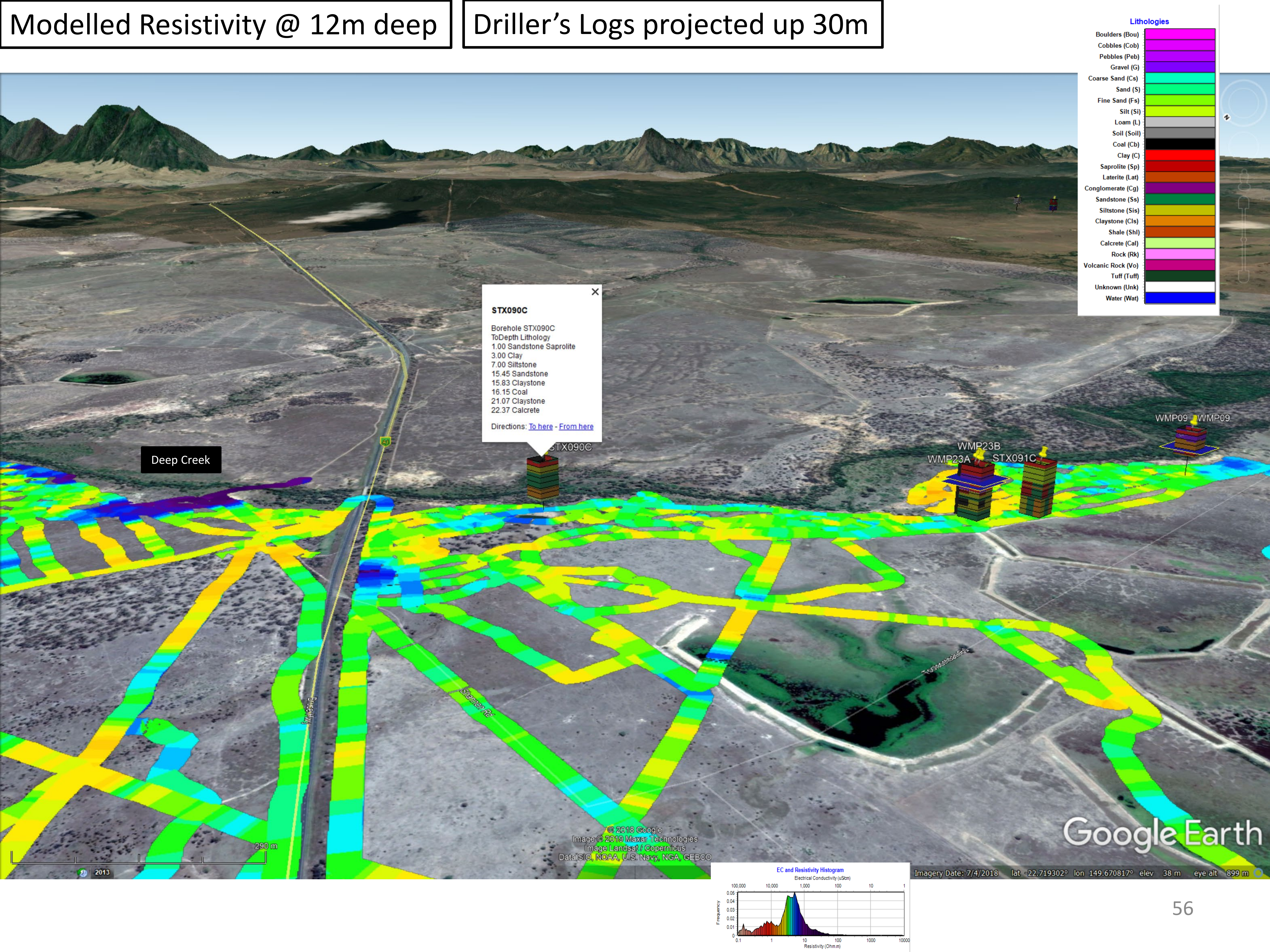
WMP27

Borehole WMP27
Water Level 20.59
ToDepth Lithology
1.00 Clay
2.00 Clay
4.00 Clay
5.00 Clay Fine Sand
8.00 Sand
9.00 Clay Fine Sand
13.00 Clay Fine Sand
15.00 Sand Clay
16.00 Sandstone Saprolite
20.50 Sandstone

Directions: To here - From here

Modelled Resistivity @ 12m deep

Driller's Logs projected up 30m



STX090C

Borehole STX090C
ToDepth Lithology
1.00 Sandstone Saprolite
3.00 Clay
7.00 Siltstone
15.45 Sandstone
15.83 Claystone
16.15 Coal
21.07 Claystone
22.37 Calcrete

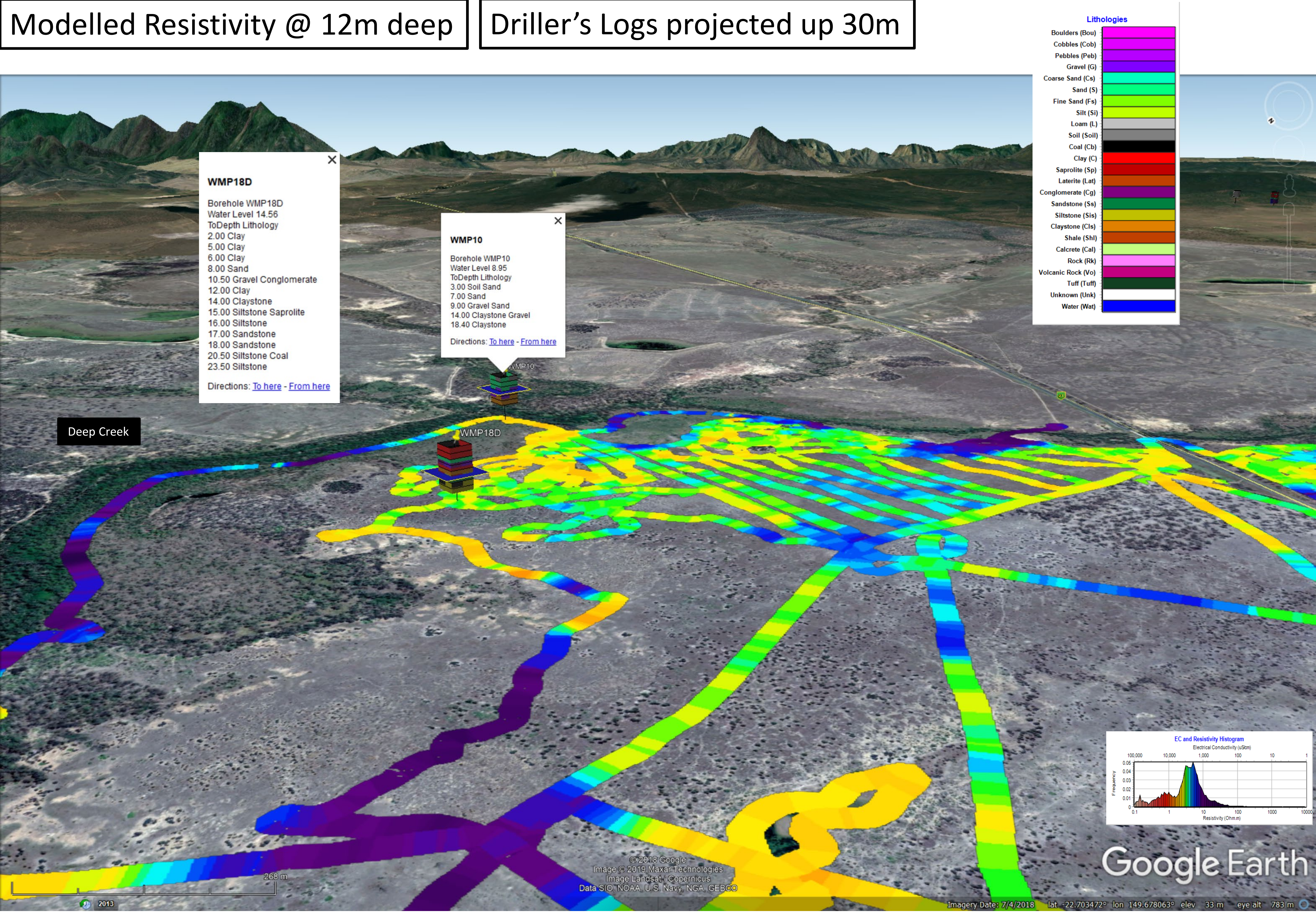
Directions: To here - From here

Lithologies

Boulders (Bou)
Cobbles (Cob)
Pebbles (Peb)
Gravel (G)
Coarse Sand (Cs)
Sand (S)
Fine Sand (Fs)
Silt (Si)
Loam (L)
Soil (Soil)
Coal (Cb)
Clay (C)
Saprolite (Sp)
Laterite (Lat)
Conglomerate (Cg)
Sandstone (Ss)
Siltstone (Sis)
Claystone (Cls)
Shale (Shl)
Calcrete (Cal)
Rock (Rk)
Volcanic Rock (Vo)
Tuff (Tuff)
Unknown (Unk)
Water (Wat)

Modelled Resistivity @ 12m deep

Driller's Logs projected up 30m



WMP18D

Borehole WMP18D
Water Level 14.56
ToDepth Lithology
2.00 Clay
5.00 Clay
6.00 Clay
8.00 Sand
10.50 Gravel Conglomerate
12.00 Clay
14.00 Claystone
15.00 Siltstone Saprolite
16.00 Siltstone
17.00 Sandstone
18.00 Sandstone
20.50 Siltstone Coal
23.50 Siltstone

Directions: To here - From here

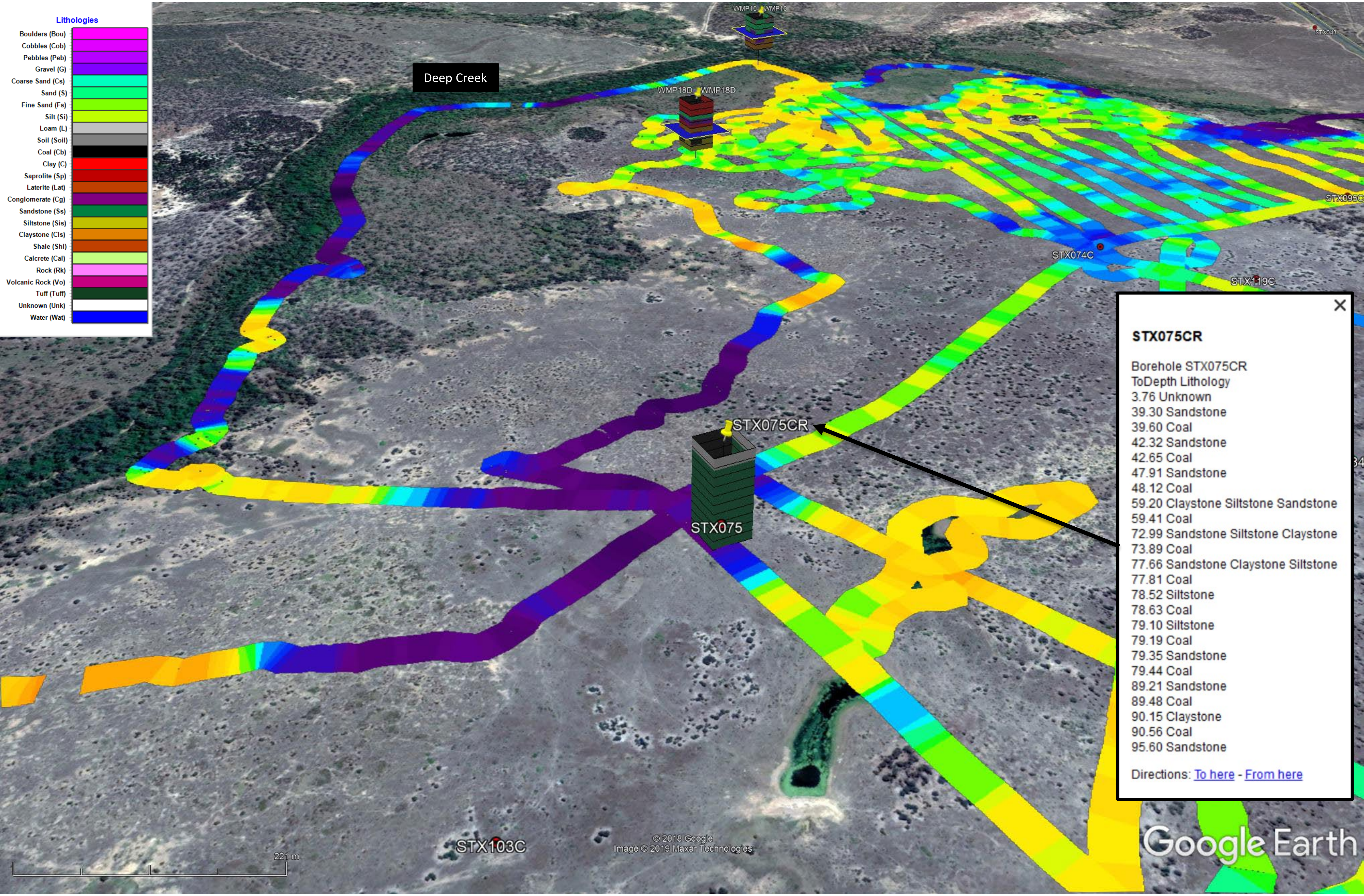
WMP10

Borehole WMP10
Water Level 8.95
ToDepth Lithology
3.00 Soil Sand
7.00 Sand
9.00 Gravel Sand
14.00 Claystone Gravel
18.40 Claystone

Directions: To here - From here

Modelled Resistivity @ 12m deep

Driller's Logs projected up 30m



STX075CR

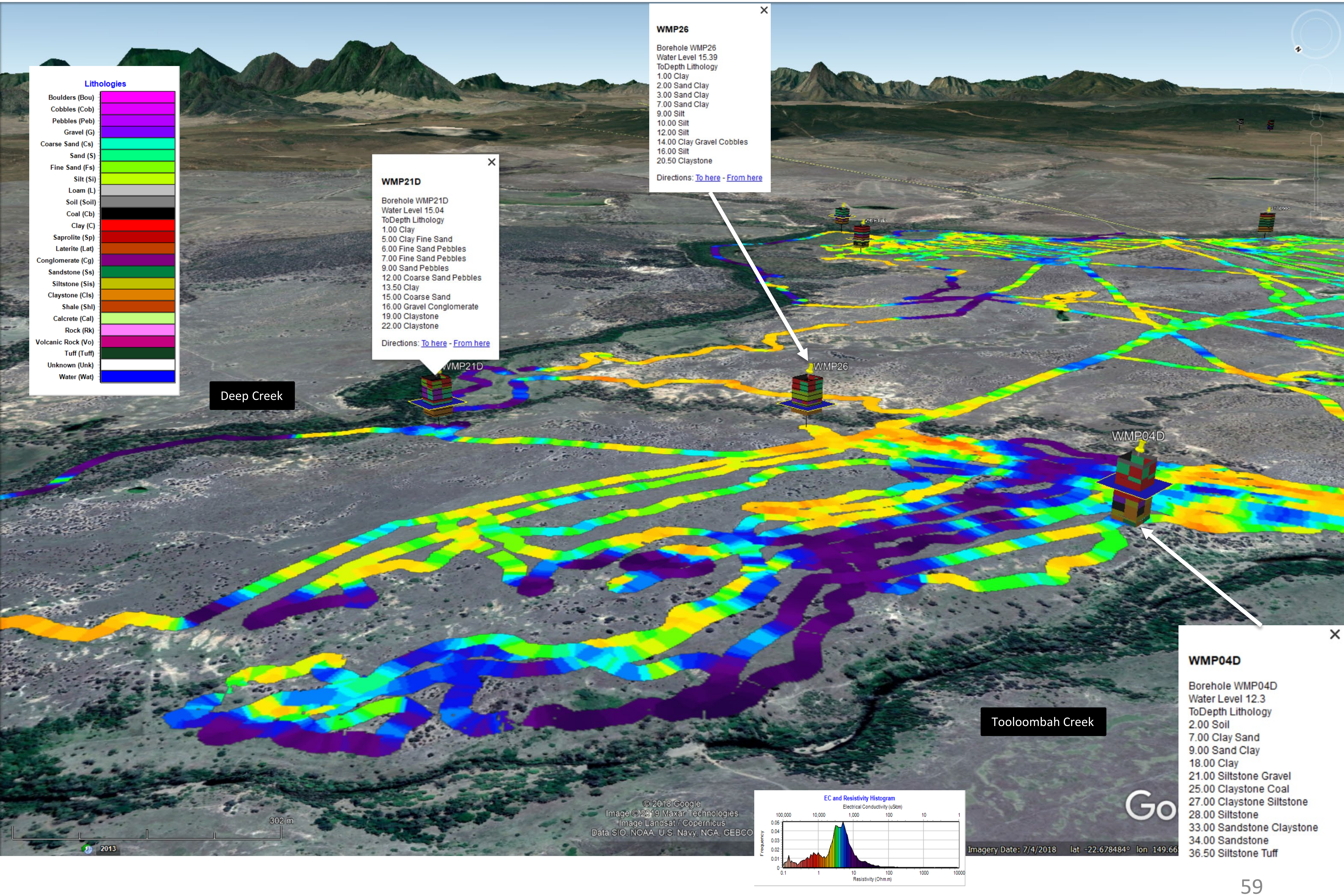
Borehole STX075CR

ToDepth	Lithology
3.76	Unknown
39.30	Sandstone
39.60	Coal
42.32	Sandstone
42.65	Coal
47.91	Sandstone
48.12	Coal
59.20	Claystone Siltstone Sandstone
59.41	Coal
72.99	Sandstone Siltstone Claystone
73.89	Coal
77.66	Sandstone Claystone Siltstone
77.81	Coal
78.52	Siltstone
78.63	Coal
79.10	Siltstone
79.19	Coal
79.35	Sandstone
79.44	Coal
89.21	Sandstone
89.48	Coal
90.15	Claystone
90.56	Coal
95.60	Sandstone

Directions: To here - From here

Modelled Resistivity @ 12m deep

Driller's Logs projected up 30m



WMP26

Borehole WMP26
Water Level 15.39
ToDepth Lithology
1.00 Clay
2.00 Sand Clay
3.00 Sand Clay
7.00 Sand Clay
9.00 Silt
10.00 Silt
12.00 Silt
14.00 Clay Gravel Cobbles
16.00 Silt
20.50 Claystone

Directions: To here - From here

WMP21D

Borehole WMP21D
Water Level 15.04
ToDepth Lithology
1.00 Clay
5.00 Clay Fine Sand
6.00 Fine Sand Pebbles
7.00 Fine Sand Pebbles
9.00 Sand Pebbles
12.00 Coarse Sand Pebbles
13.50 Clay
15.00 Coarse Sand
16.00 Gravel Conglomerate
19.00 Claystone
22.00 Claystone

Directions: To here - From here

WMP04D

Borehole WMP04D
Water Level 12.3
ToDepth Lithology
2.00 Soil
7.00 Clay Sand
9.00 Sand Clay
18.00 Clay
21.00 Siltstone Gravel
25.00 Claystone Coal
27.00 Claystone Siltstone
28.00 Siltstone
33.00 Sandstone Claystone
34.00 Sandstone
36.50 Siltstone Tuff

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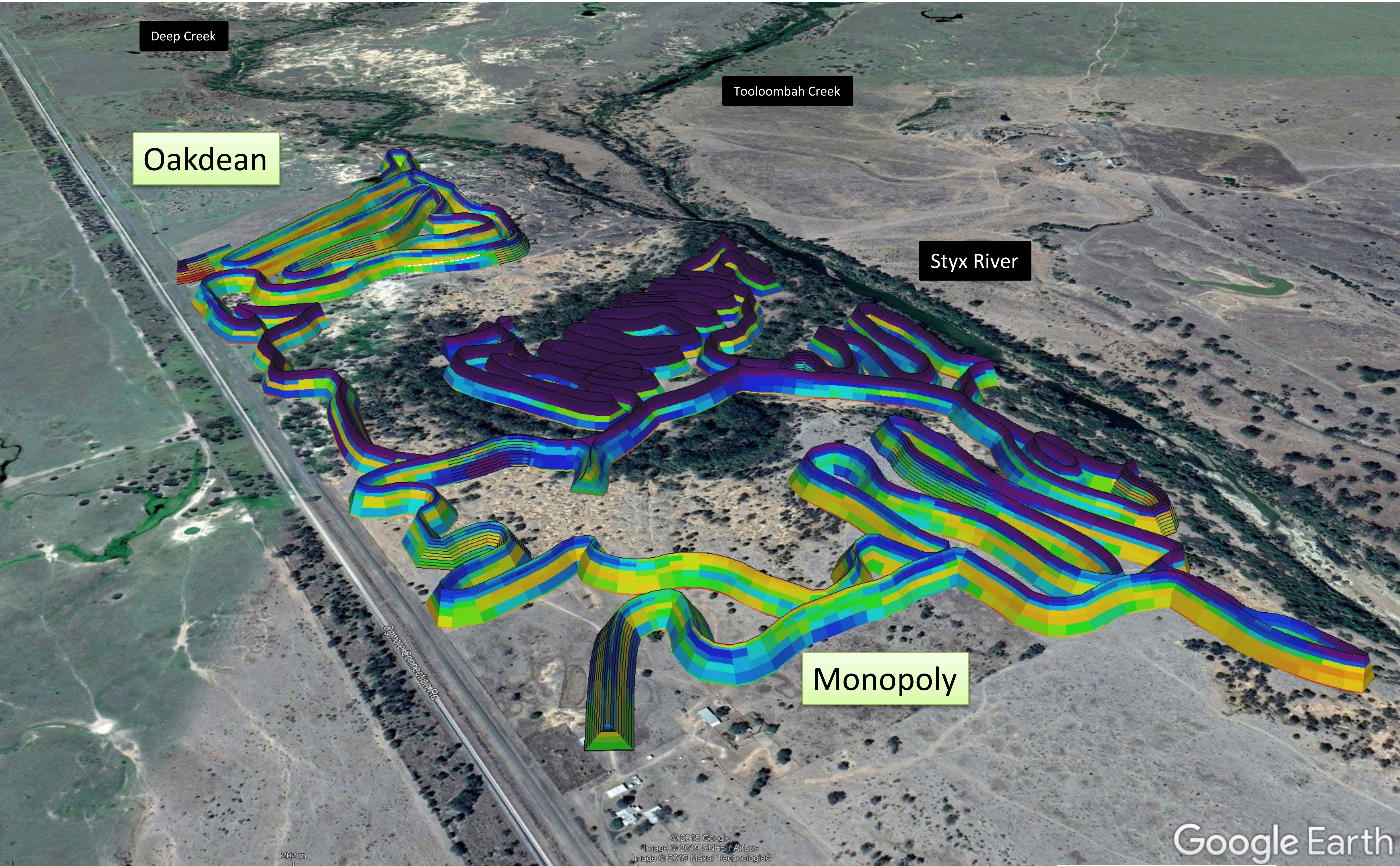
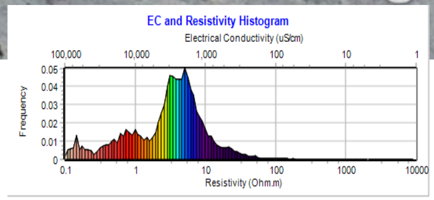
Image Landsat / Copernicus
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Modelled Resistivity projected up 30m

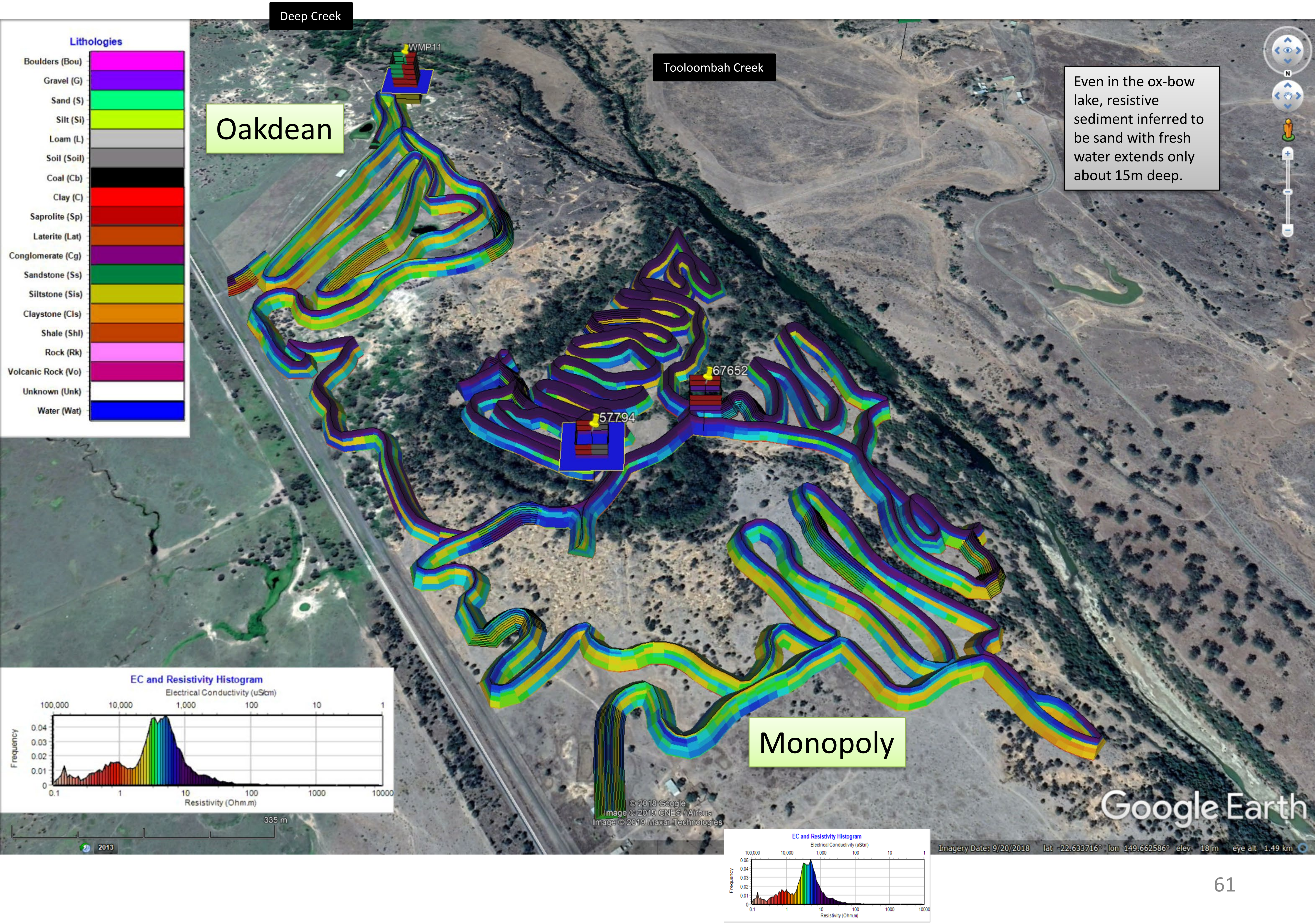
Looking south – Data segment 1 of 7





Modelled Resistivity projected up 30m

Looking south



Even in the ox-bow lake, resistive sediment inferred to be sand with fresh water extends only about 15m deep.

Modelled Resistivity projected up 30m

Mamelon North - Looking South – Data segment 2/7

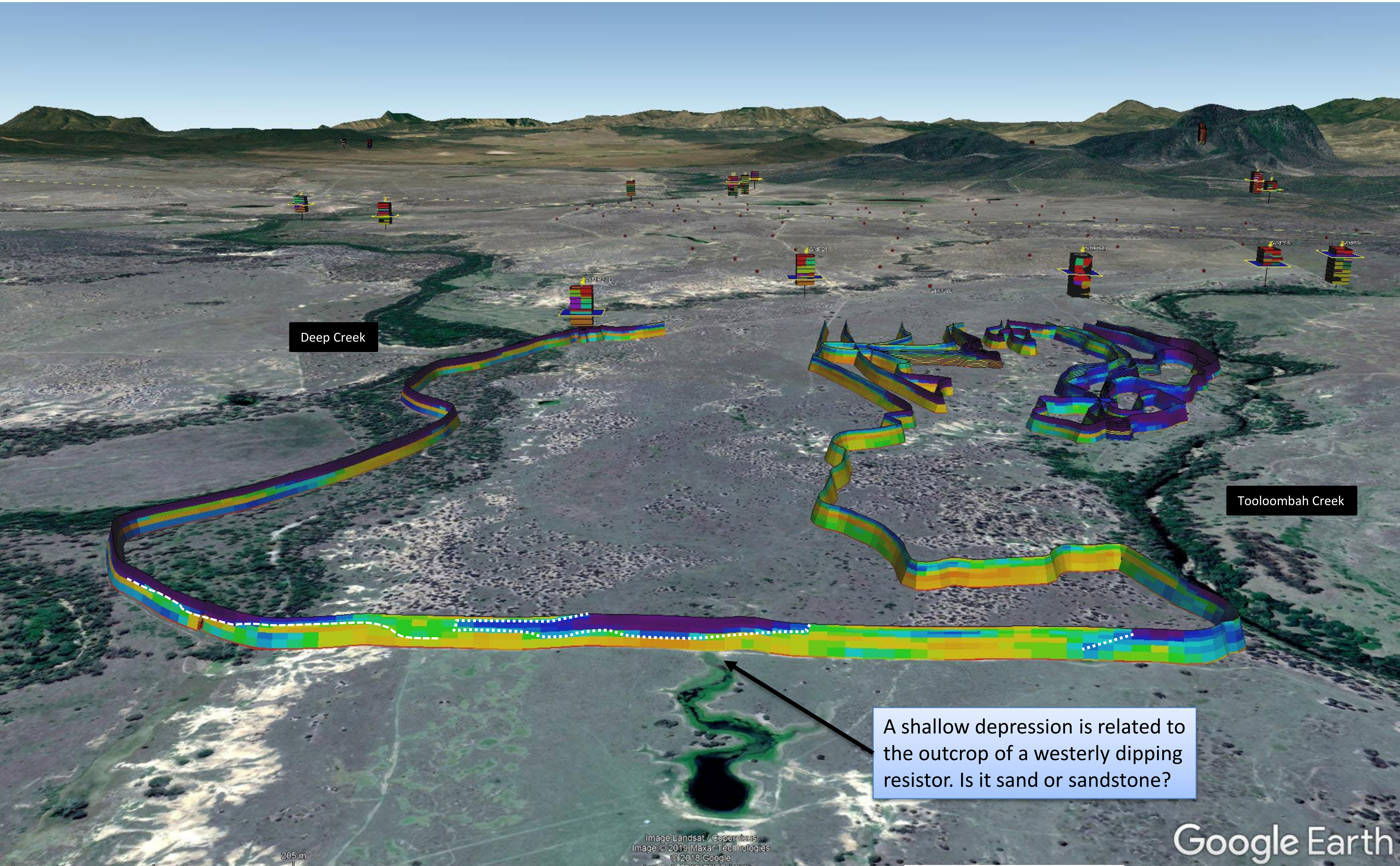


Image Landsat / Copernicus
Image © 2019 Maxar Technologies
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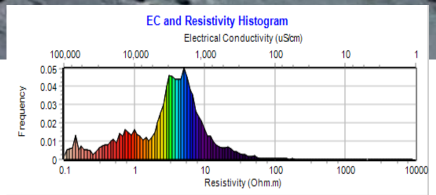
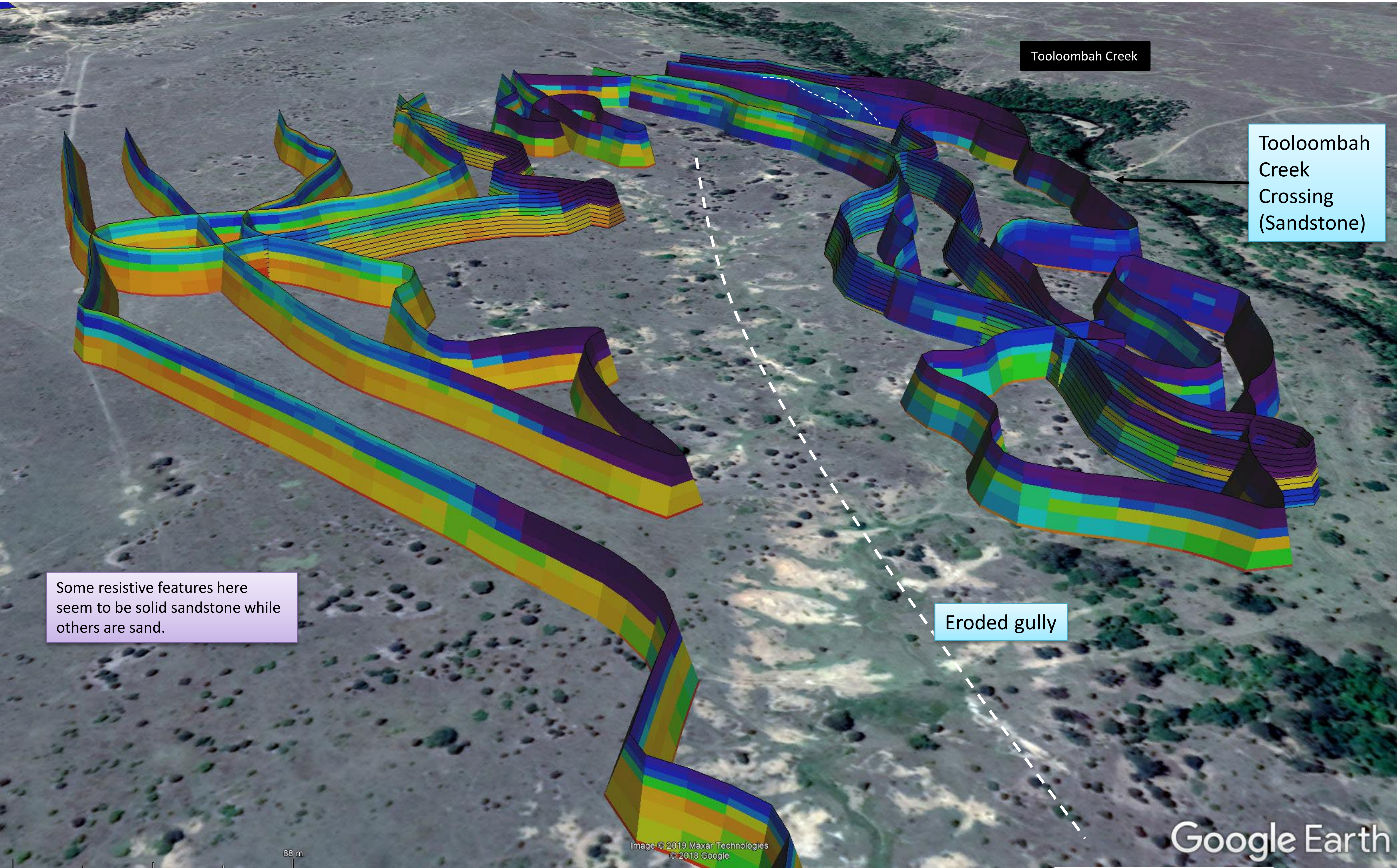
Image © 2019 CNES / Airbus

A shallow depression is related to the outcrop of a westerly dipping resistor. Is it sand or sandstone?



Modelled Resistivity projected up 30m

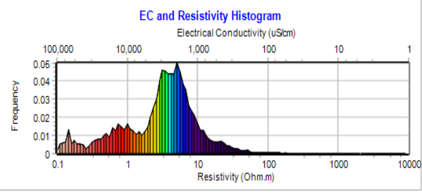
Tooloombah Creek – Mamelon North - Looking South



Tooloombah Creek Crossing (Sandstone)

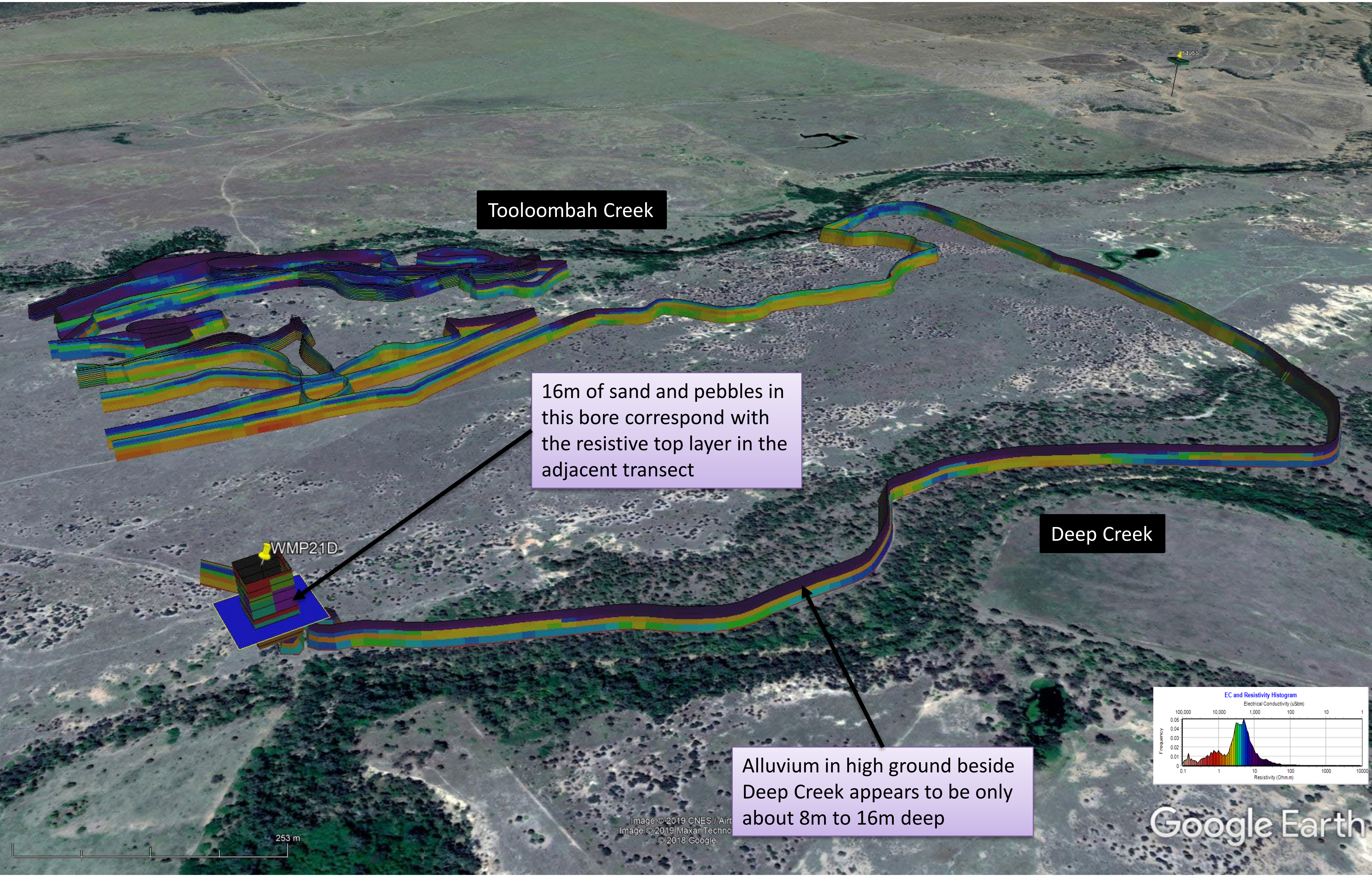
Eroded gully

Some resistive features here seem to be solid sandstone while others are sand.



Modelled Resistivity projected up 30m

Mamelon North – Looking West

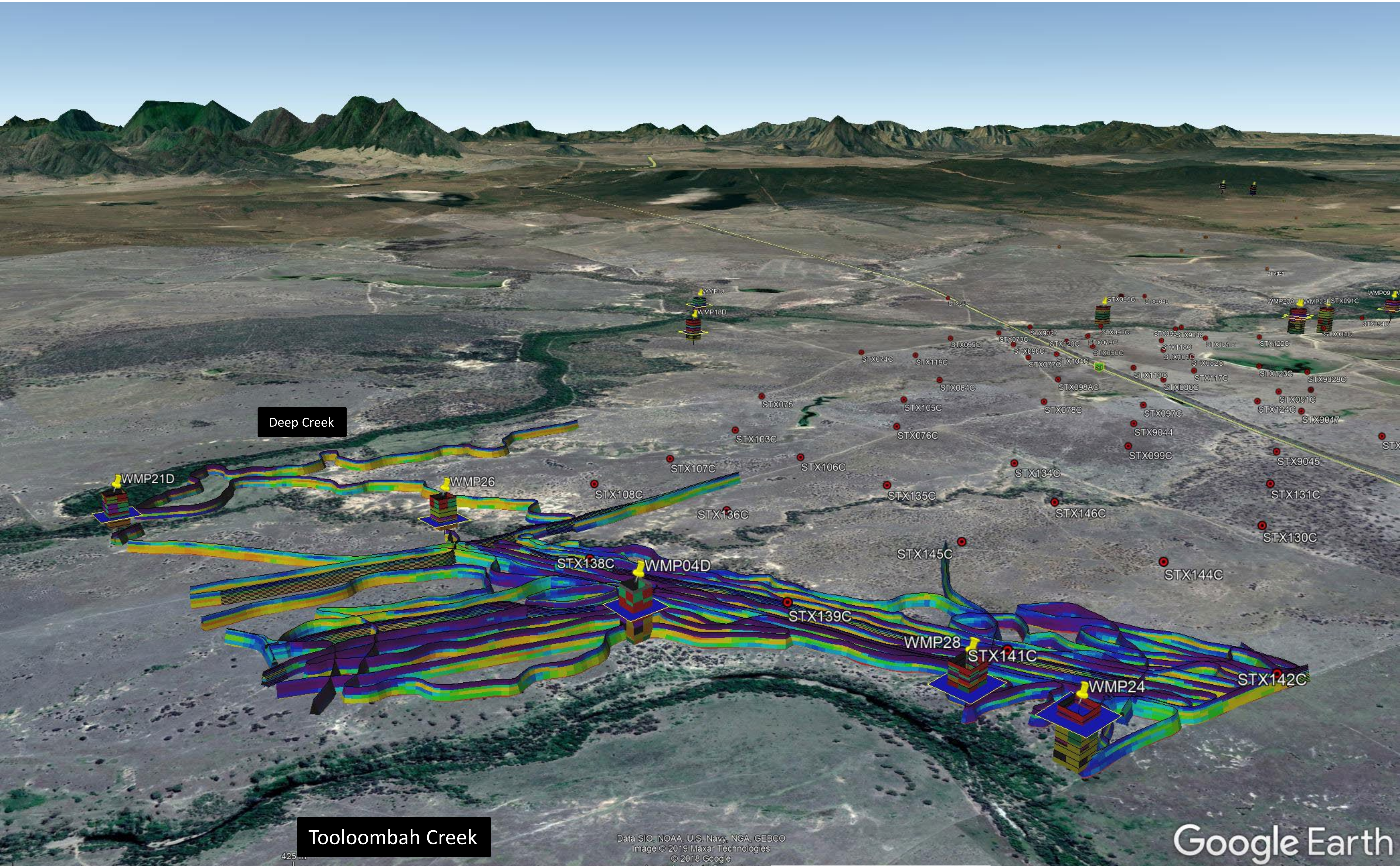


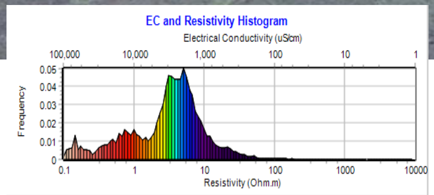
16m of sand and pebbles in this bore correspond with the resistive top layer in the adjacent transect

Alluvium in high ground beside Deep Creek appears to be only about 8m to 16m deep

Modelled Resistivity projected up 30m

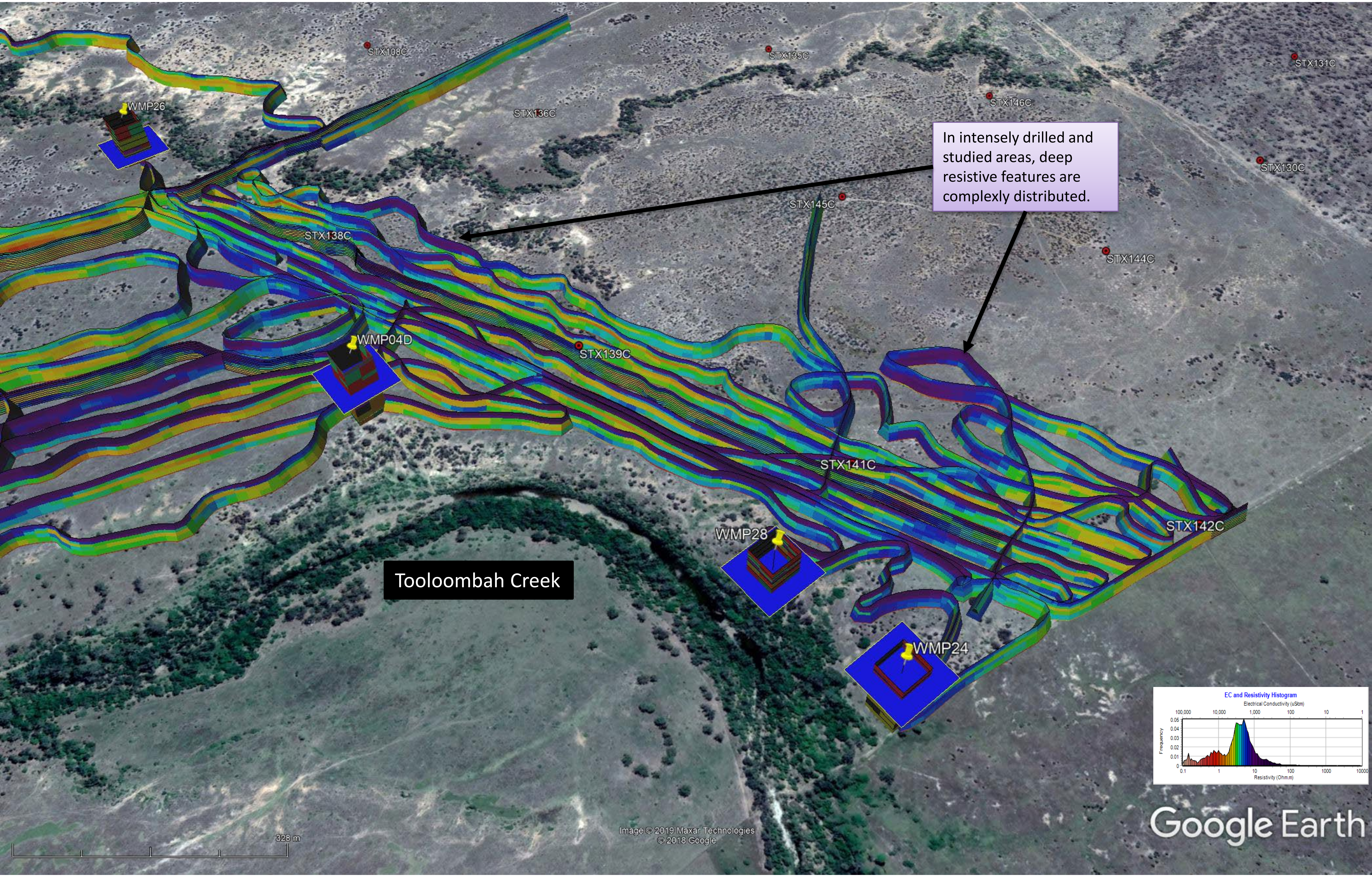
Mamelon – looking SE – Data segment 3 of 7





Modelled Resistivity projected up 30m

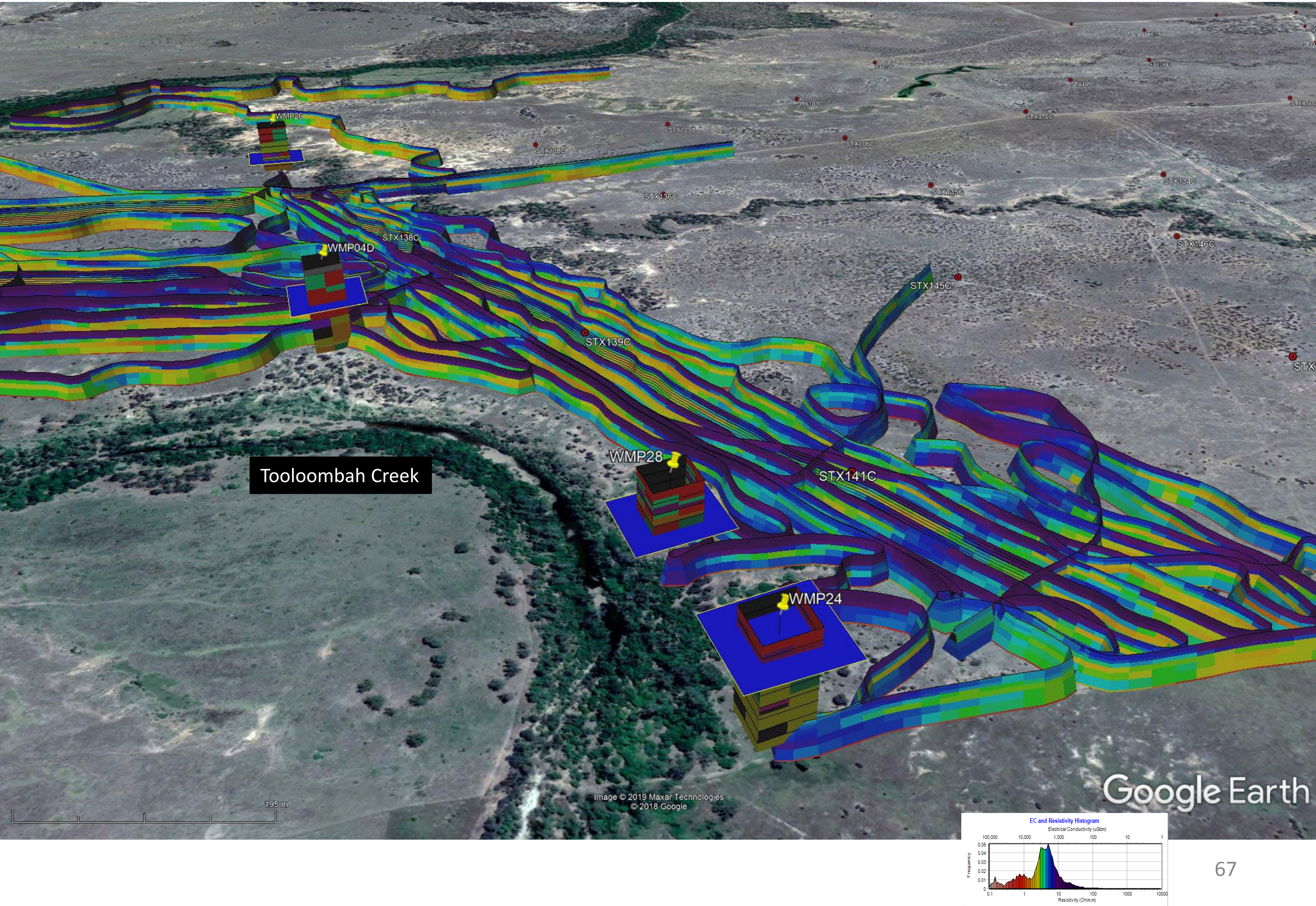
Mamelon – looking SE – Data segment 3 of 7



In intensely drilled and studied areas, deep resistive features are complexly distributed.

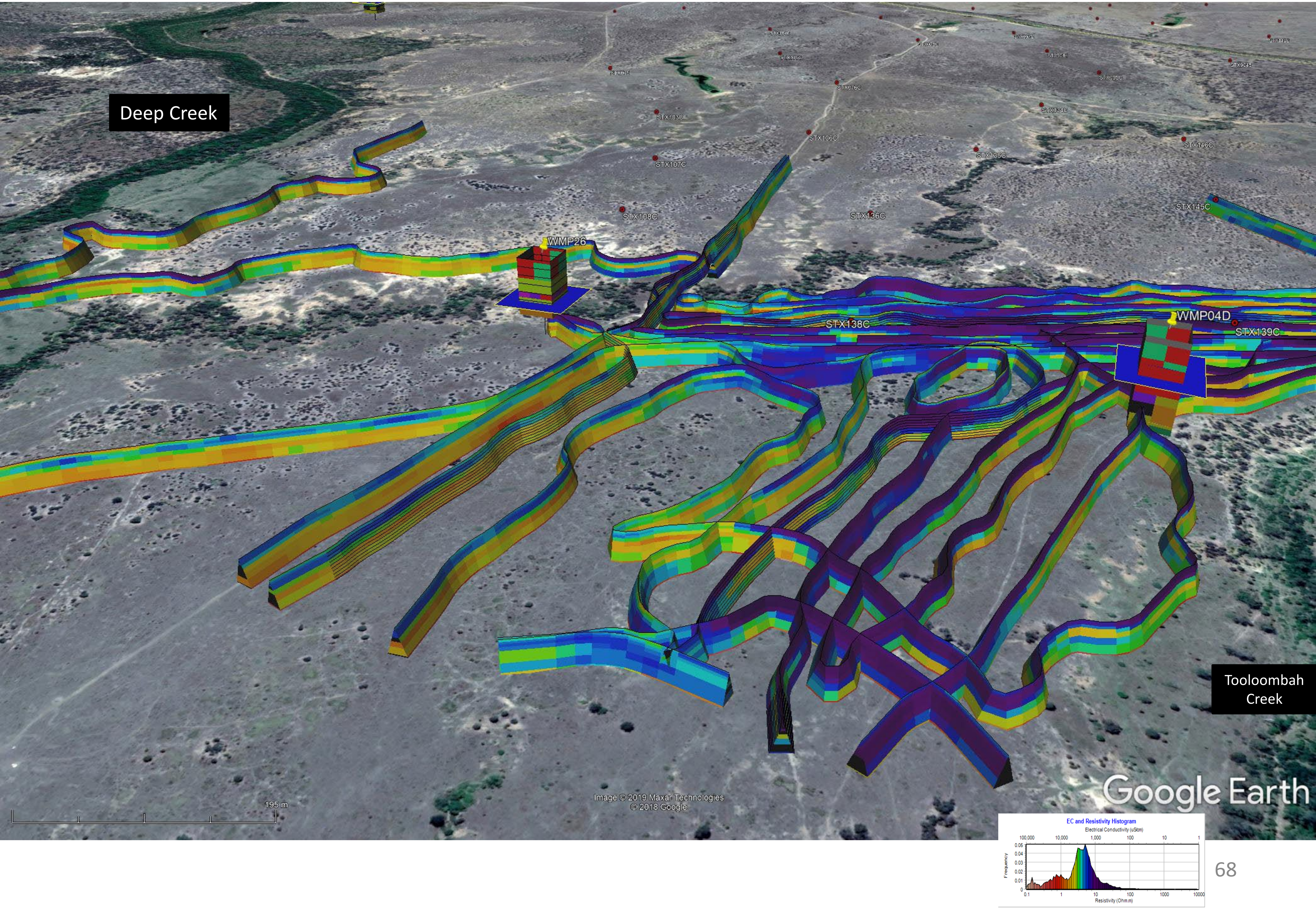
Modelled Resistivity projected up 30m

Mamelon – looking SE – Data segment 3 of 7



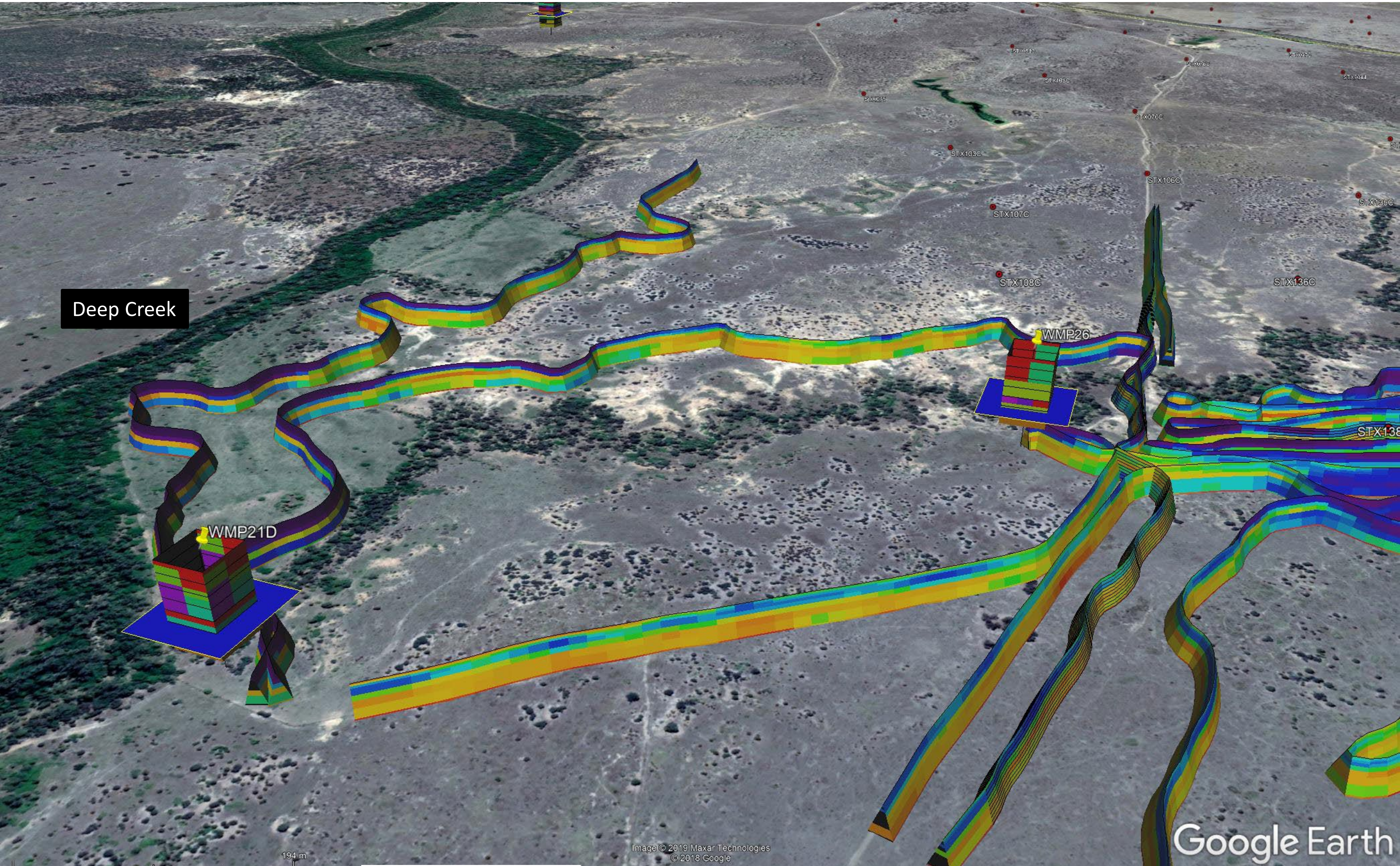
Modelled Resistivity projected up 30m

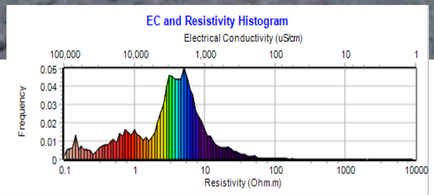
Mamelon – looking South – Data segment 3 of 7



Modelled Resistivity projected up 30m

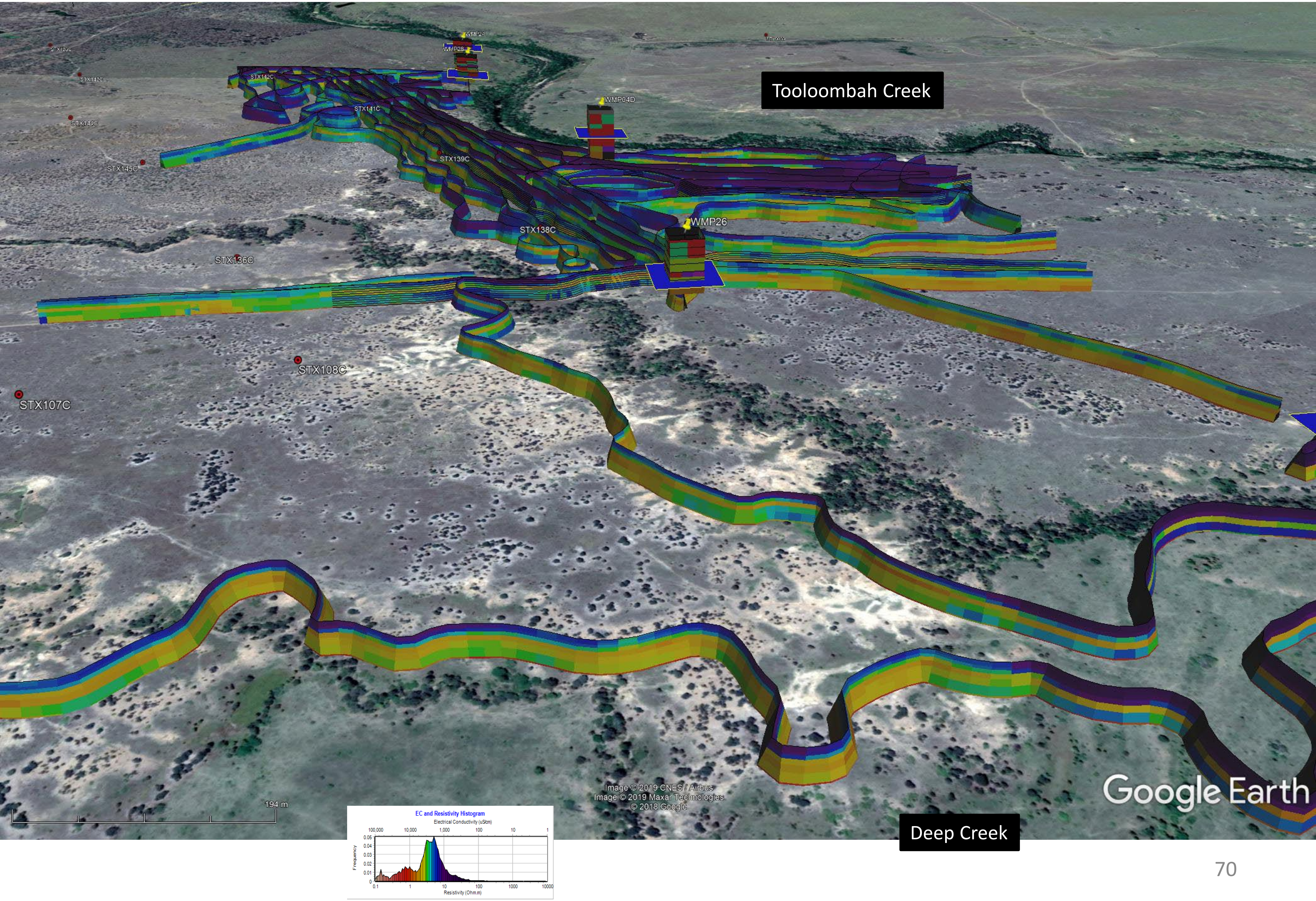
Mamelon – looking South – Data segment 3 of 7





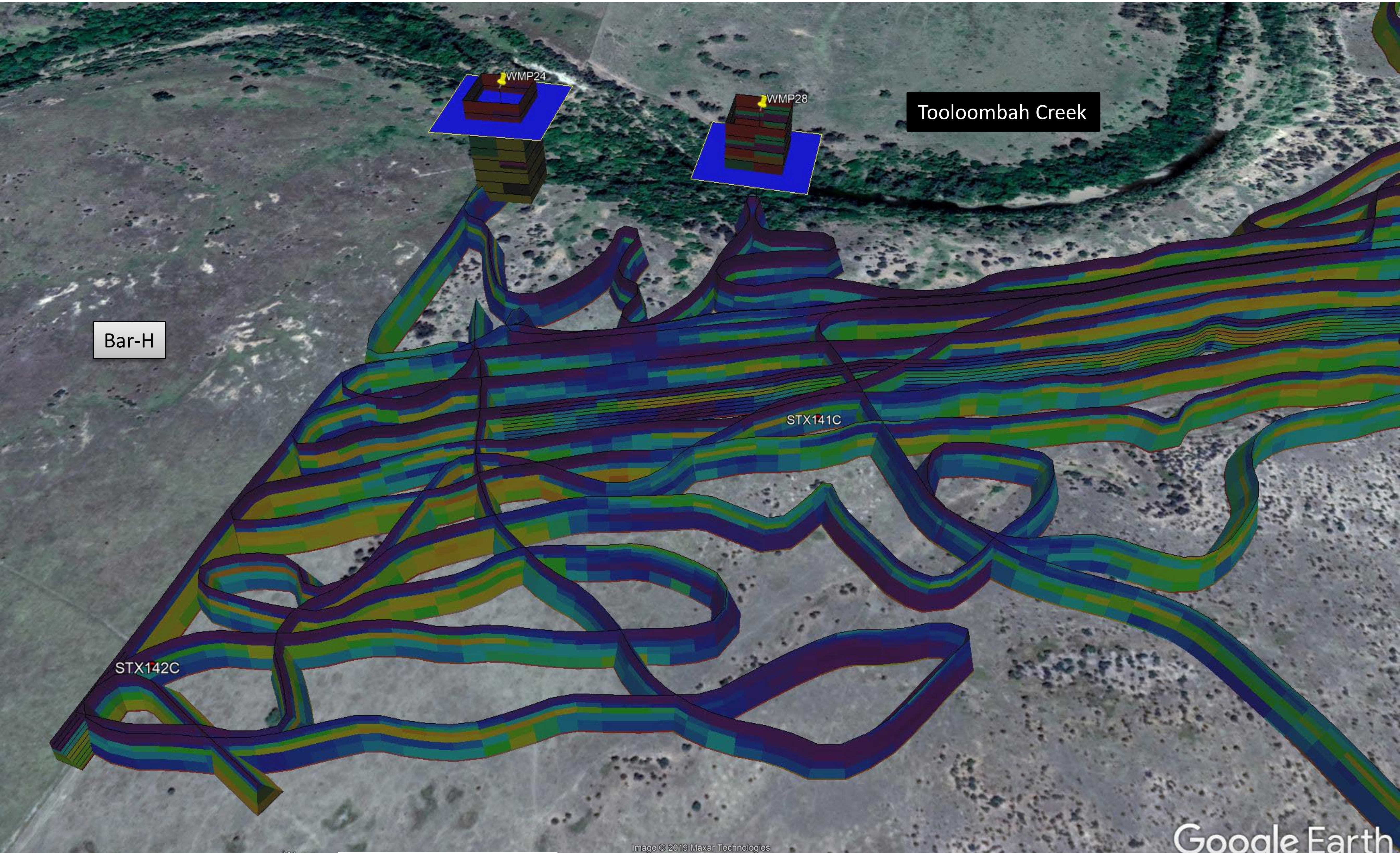
Modelled Resistivity projected up 30m

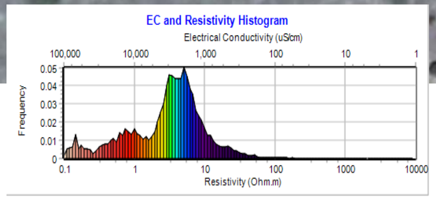
Mamelon – looking West – Data segment 3 of 7



Modelled Resistivity projected up 30m

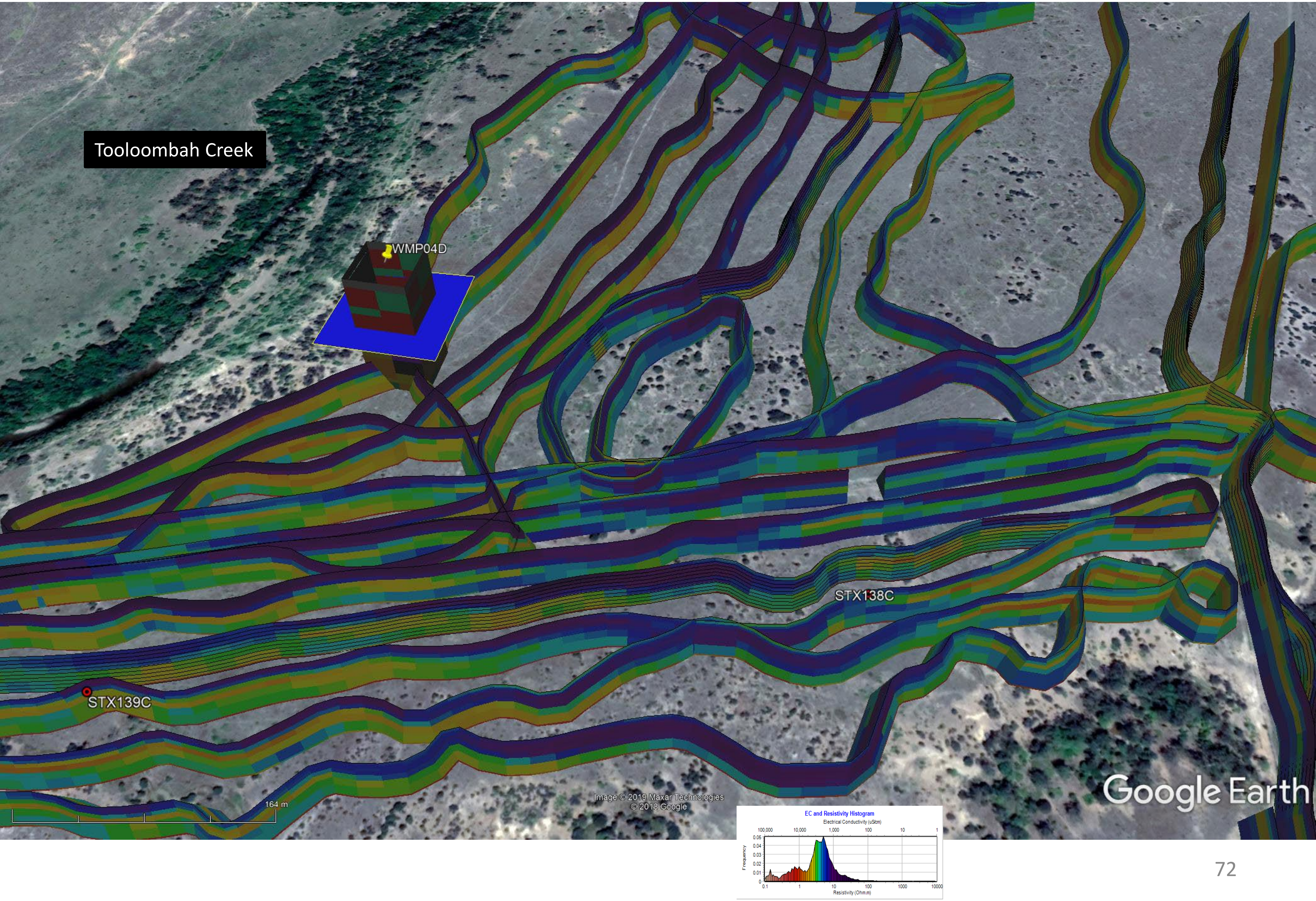
Mamelon – looking North – Data segment 3 of 7





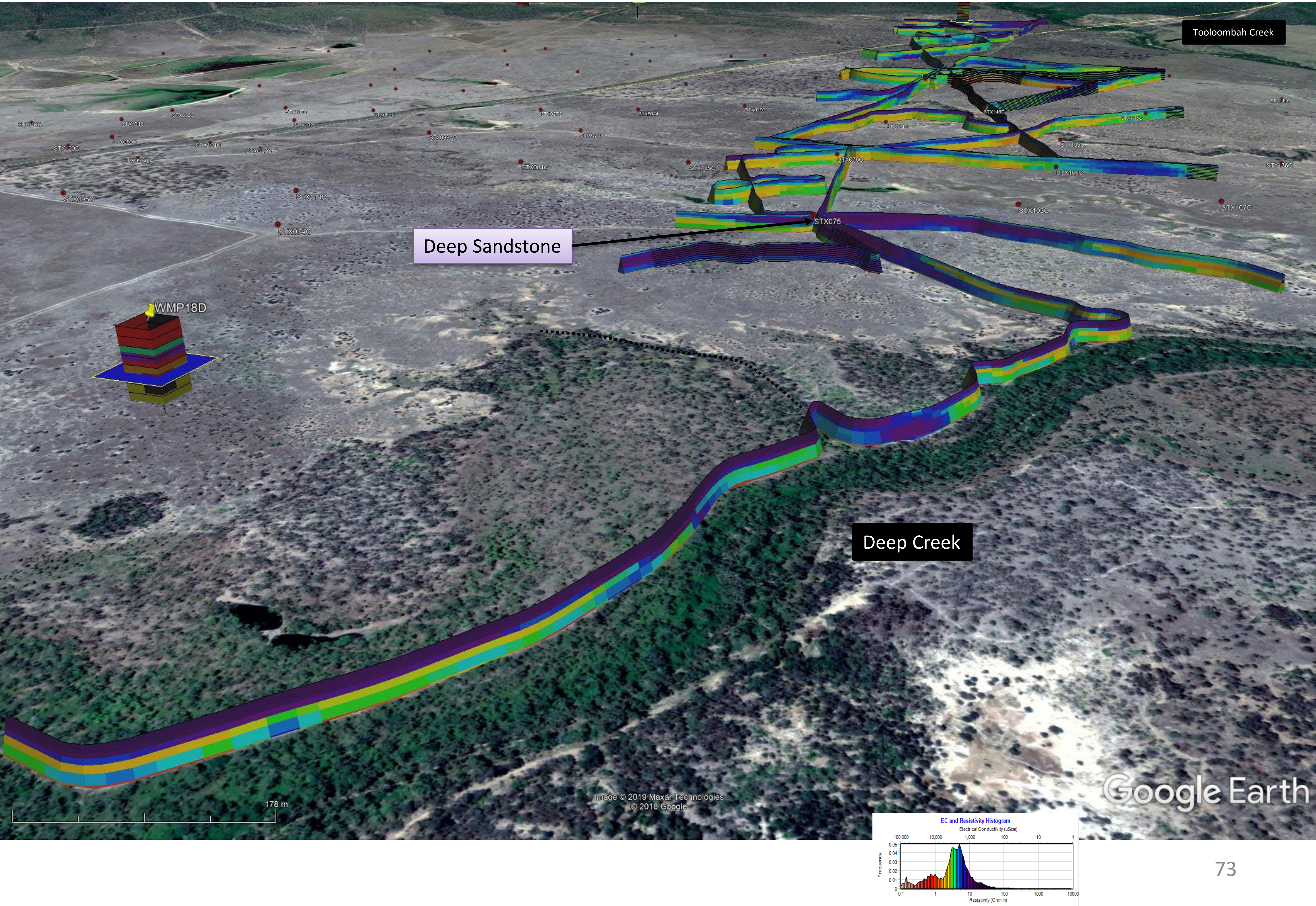
Modelled Resistivity projected up 30m

Mamelon – looking North – Data segment 3 of 7



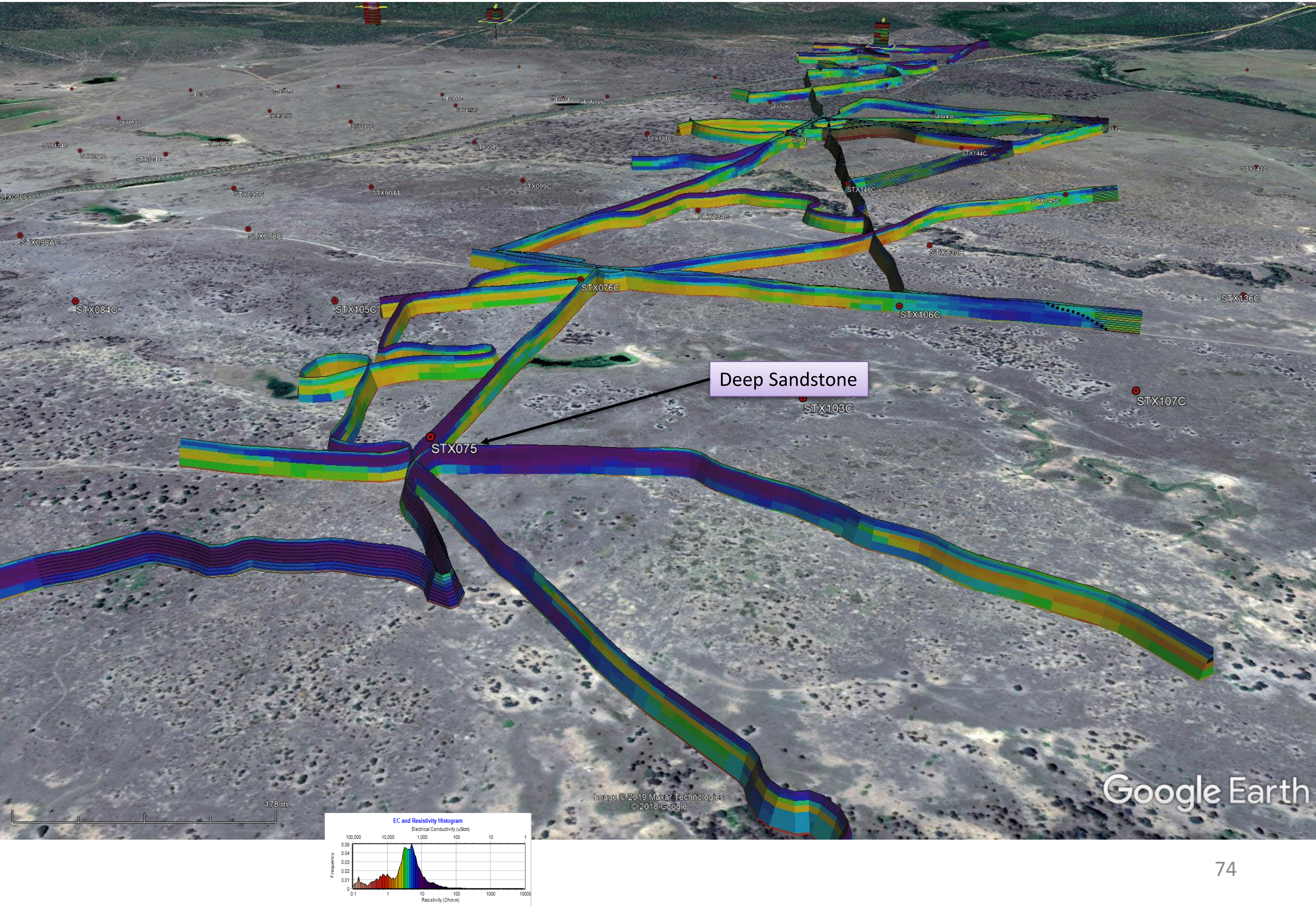
Modelled Resistivity projected up 30m

Mamelon – looking West – Data segment 4 of 7



Modelled Resistivity projected up 30m

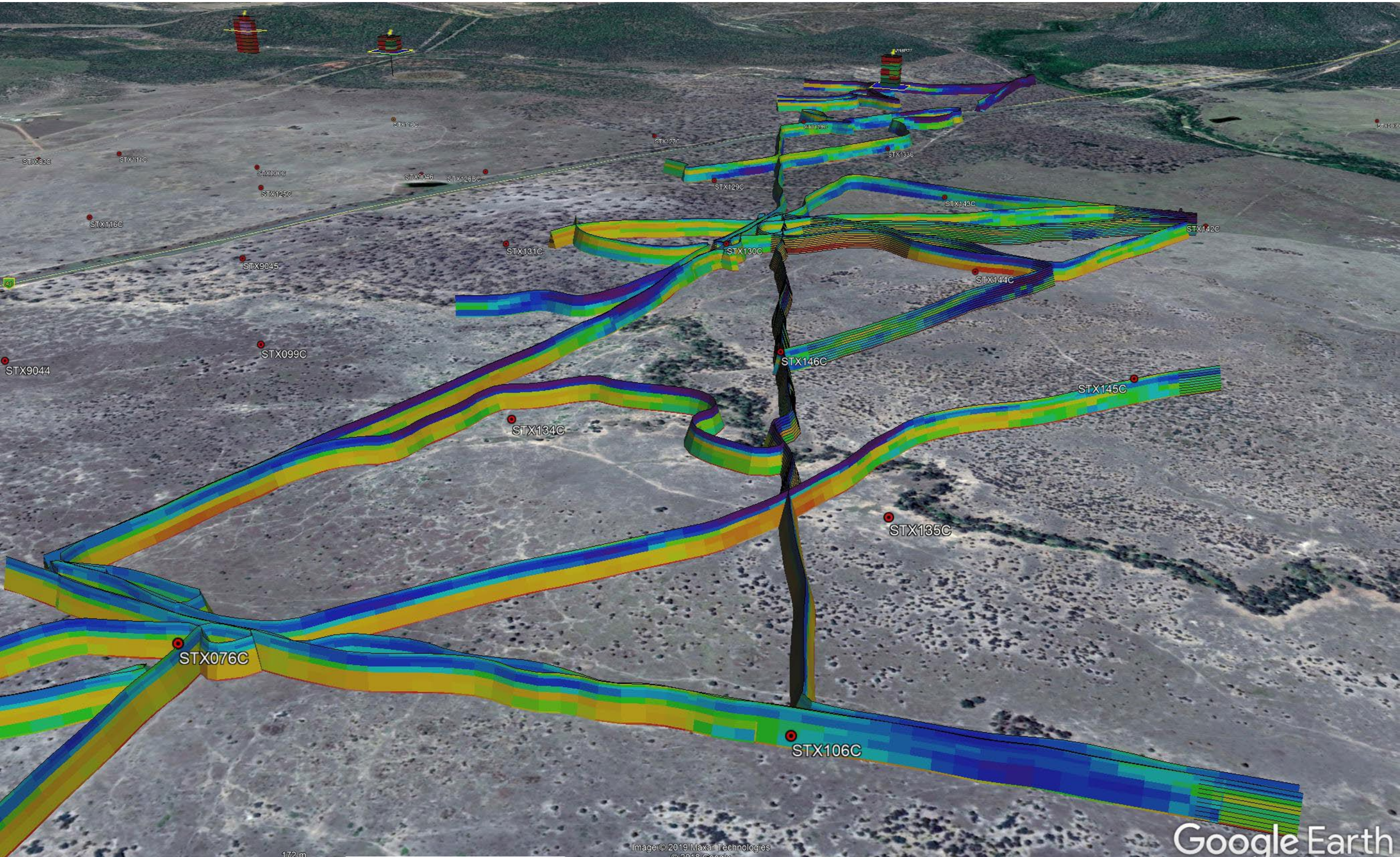
Mamelon – looking West – Data segment 4 of 7

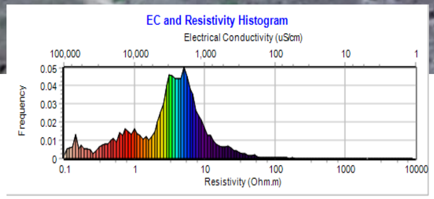


Deep Sandstone

Modelled Resistivity projected up 30m

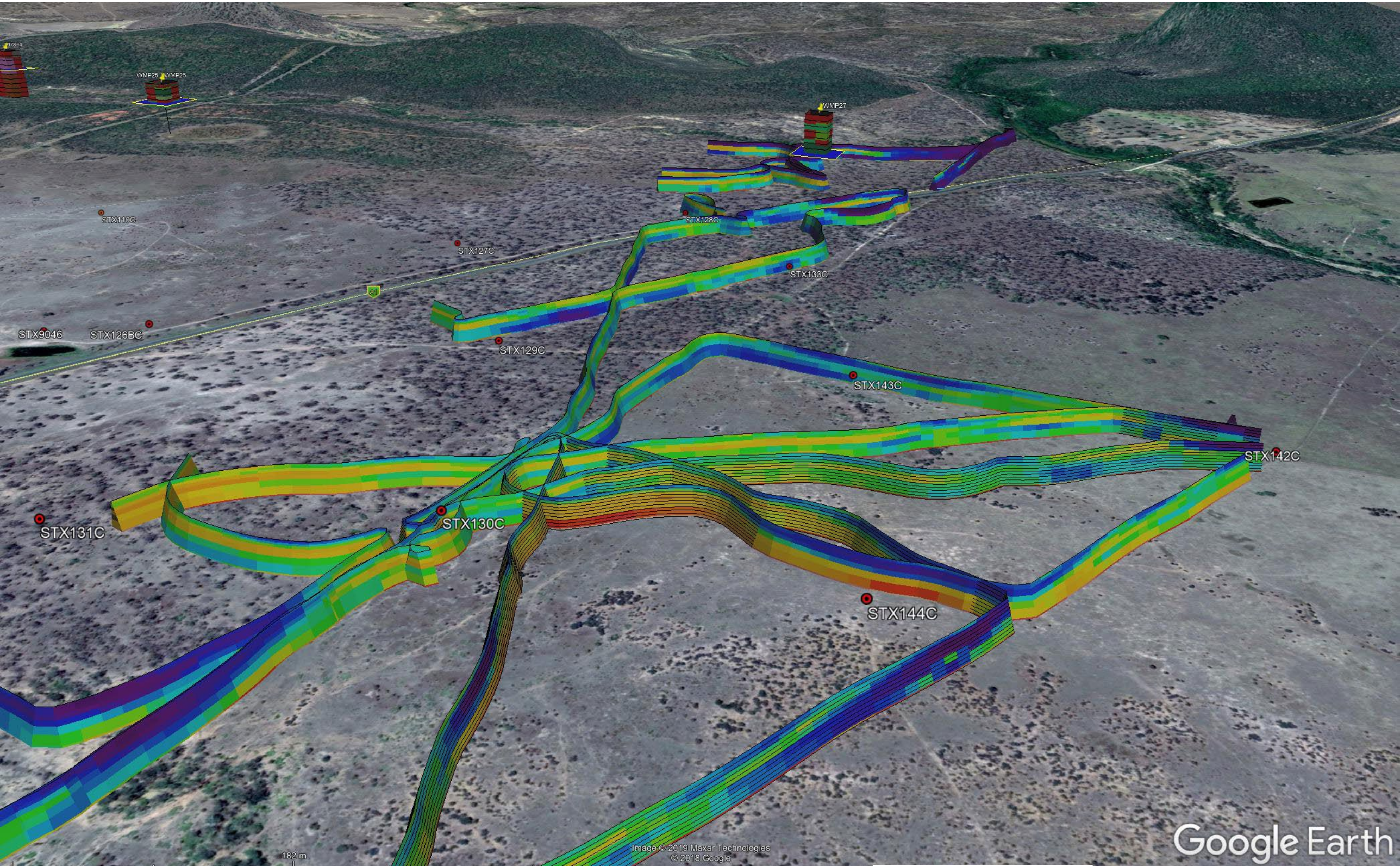
Mamelon – looking West – Data segment 4 of 7

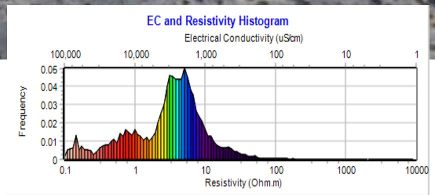




Modelled Resistivity projected up 30m

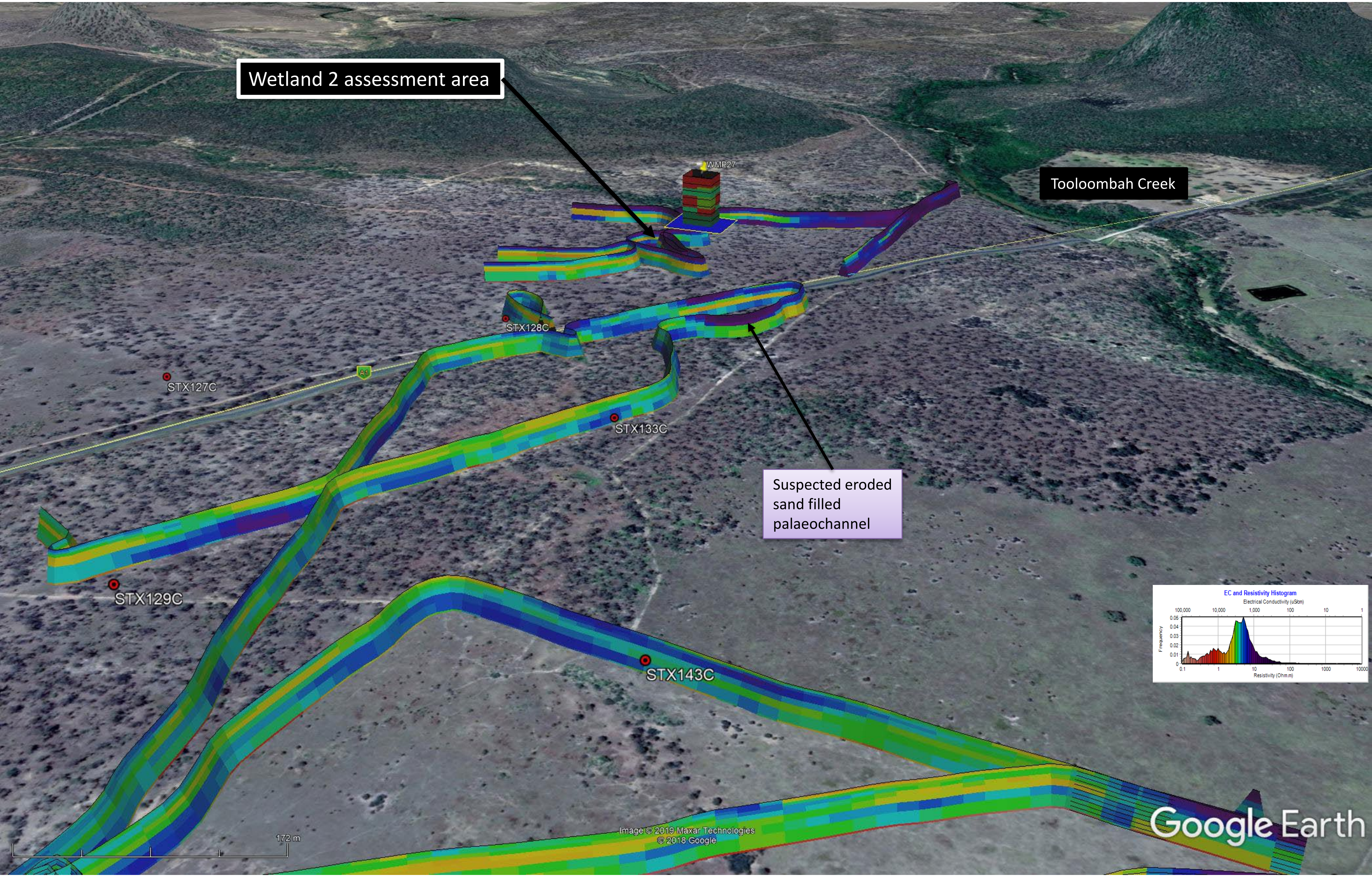
Mamelon – looking West – Data segment 4 of 7





Modelled Resistivity projected up 30m

Mamelon – looking West – Data segment 4 of 7



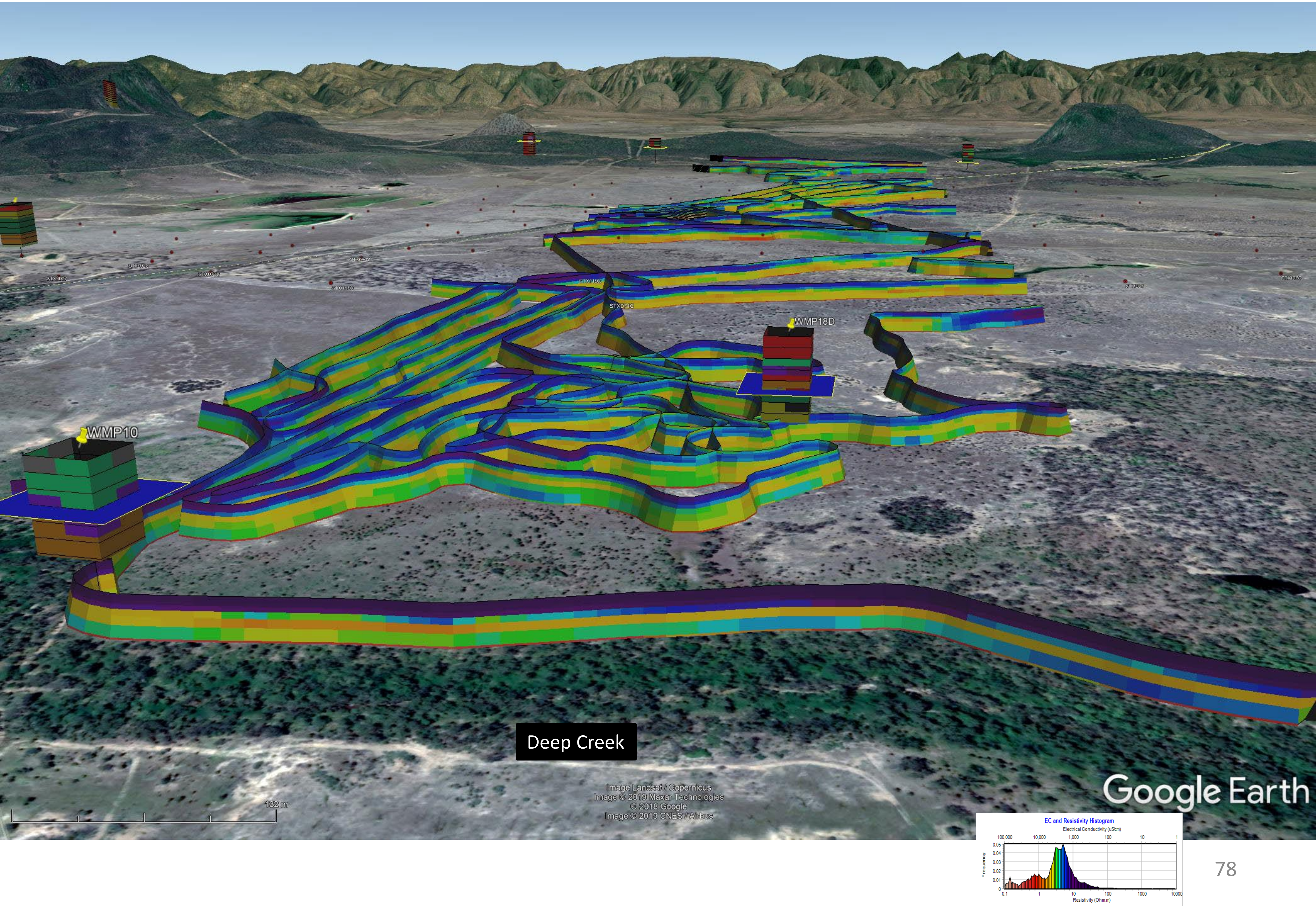
Wetland 2 assessment area

Tooloombah Creek

Suspected eroded sand filled palaeochannel

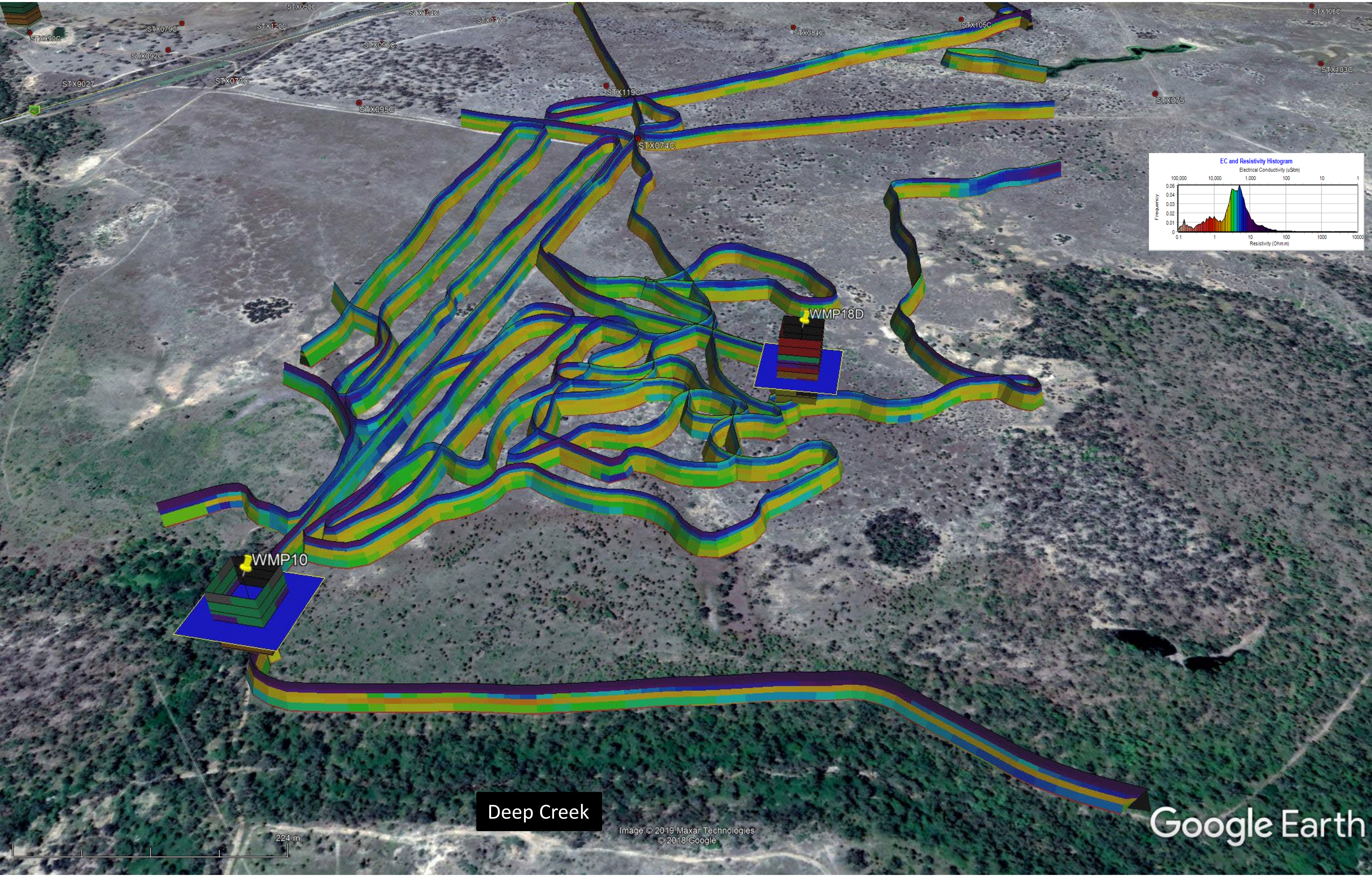
Modelled Resistivity projected up 30m

Mamelon – looking West – Data segment 5 of 7



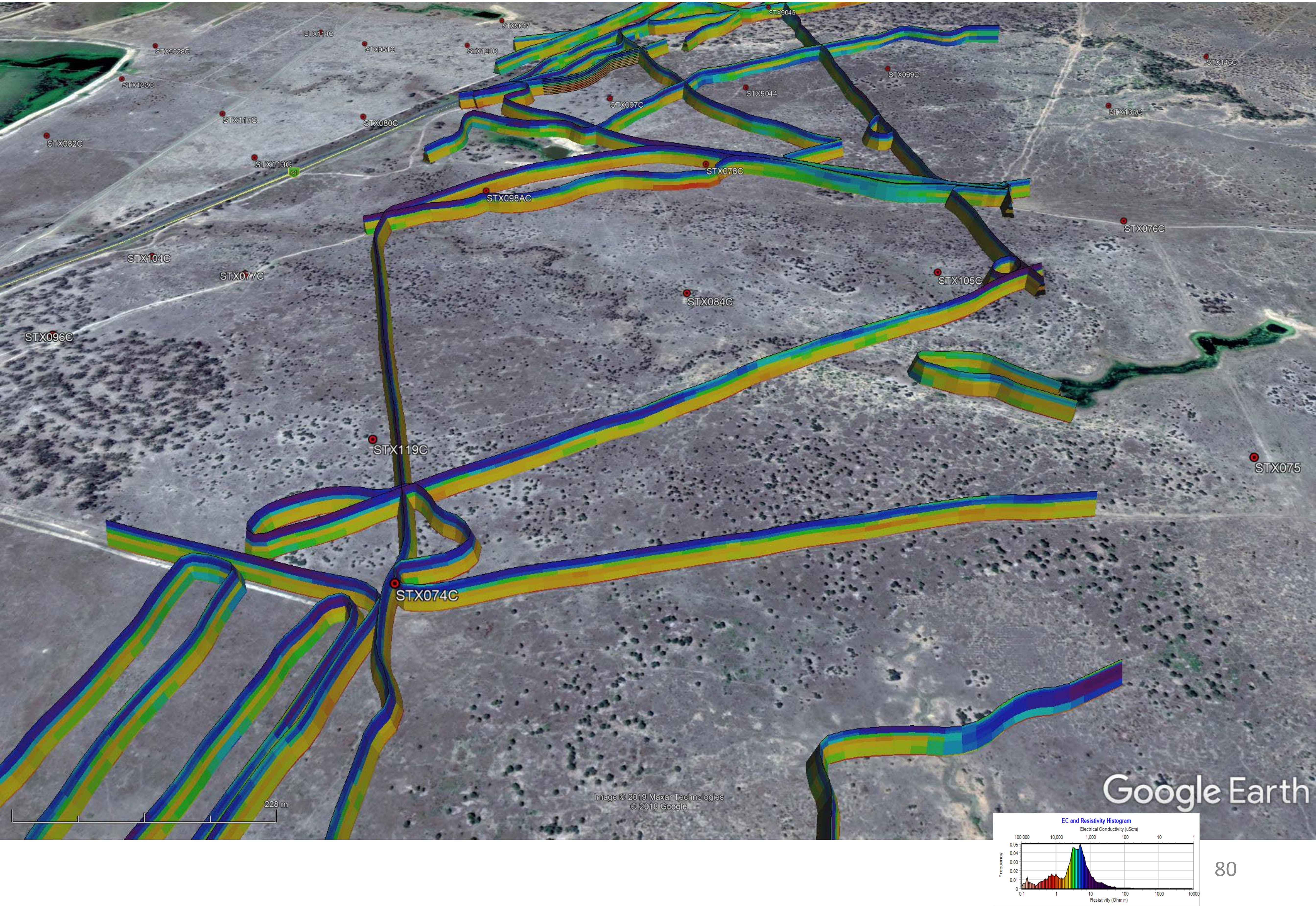
Modelled Resistivity projected up 30m

Mamelon – looking West – Data segment 5 of 7



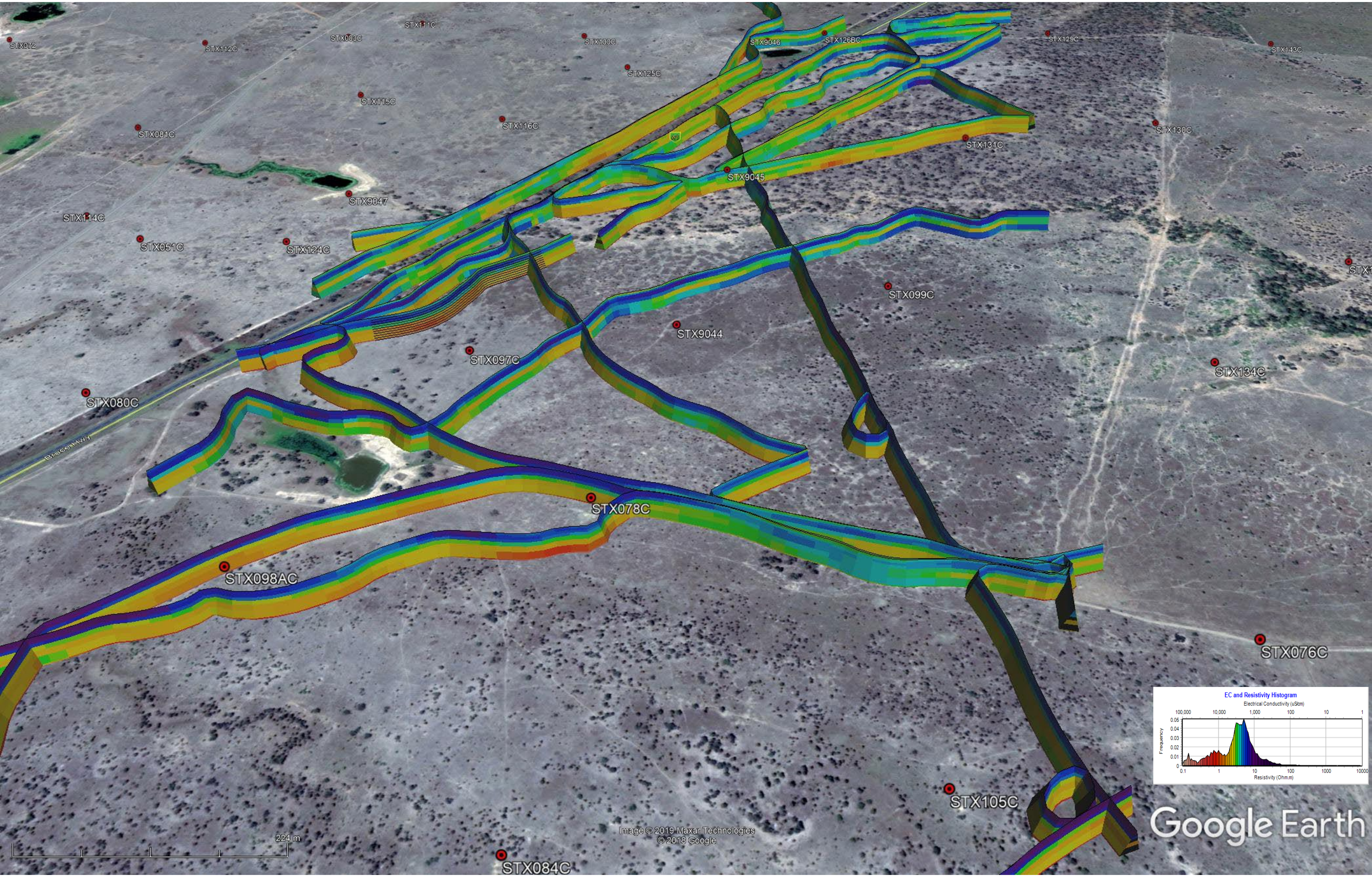
Modelled Resistivity projected up 30m

Mamelon – looking West – Data segment 5 of 7



Modelled Resistivity projected up 30m

Mamelon – looking West – Data segment 5 of 7

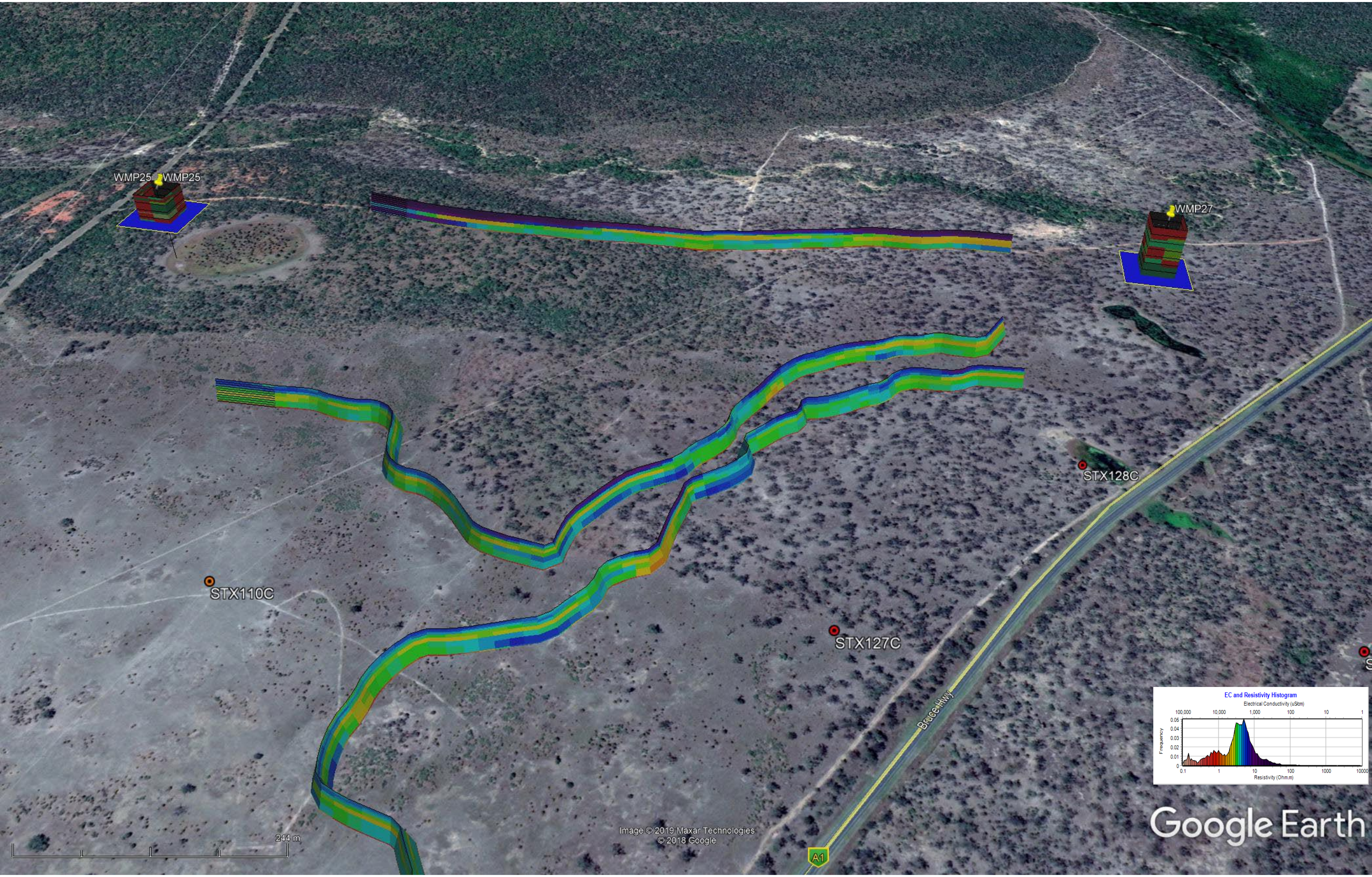


Modelled Resistivity projected up 30m

Mamelon – looking West – Data segment 5 of 7

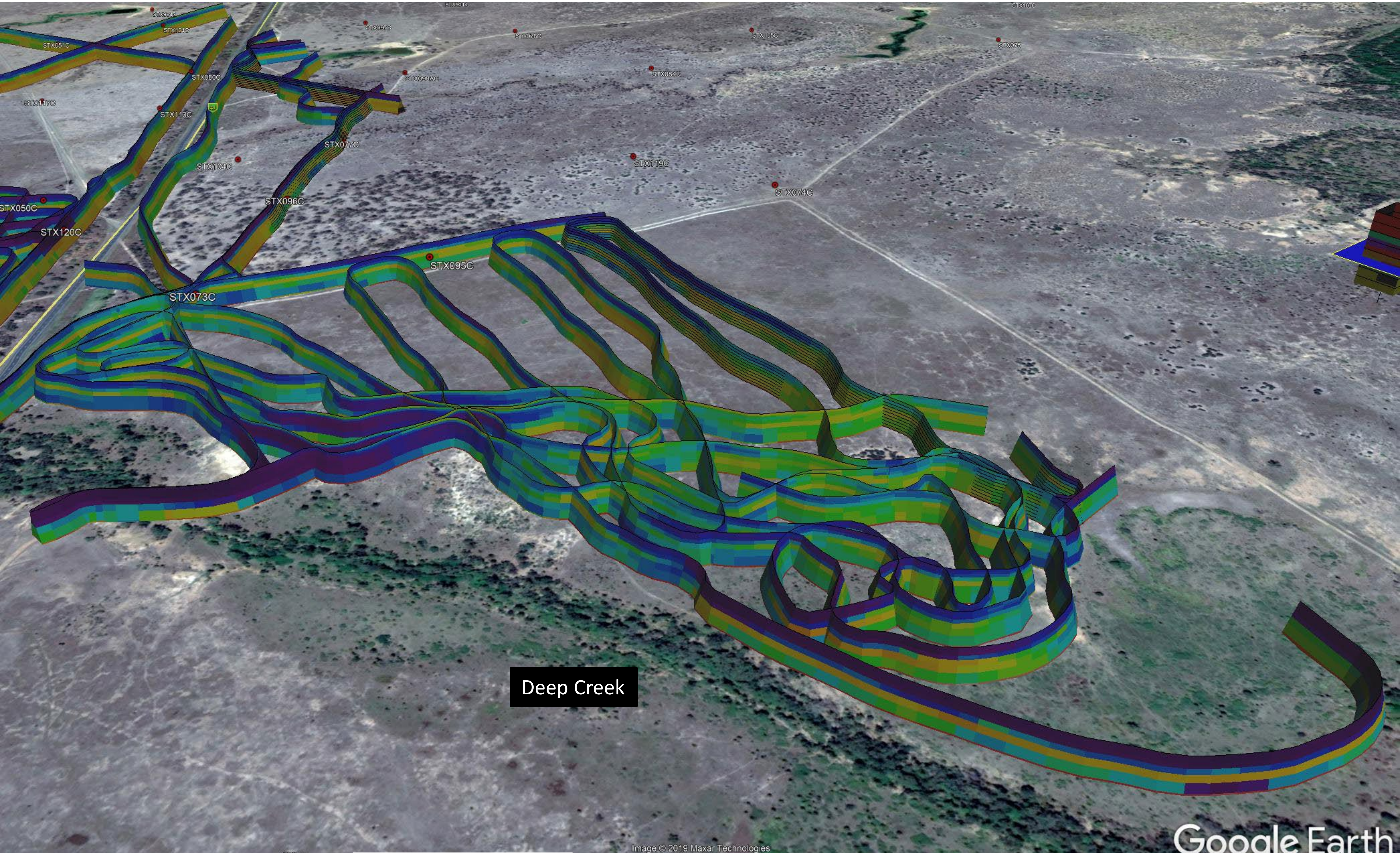
Modelled Resistivity projected up 30m

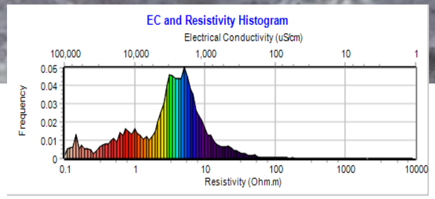
Mamelon – looking West – Data segment 5 of 7



Modelled Resistivity projected up 30m

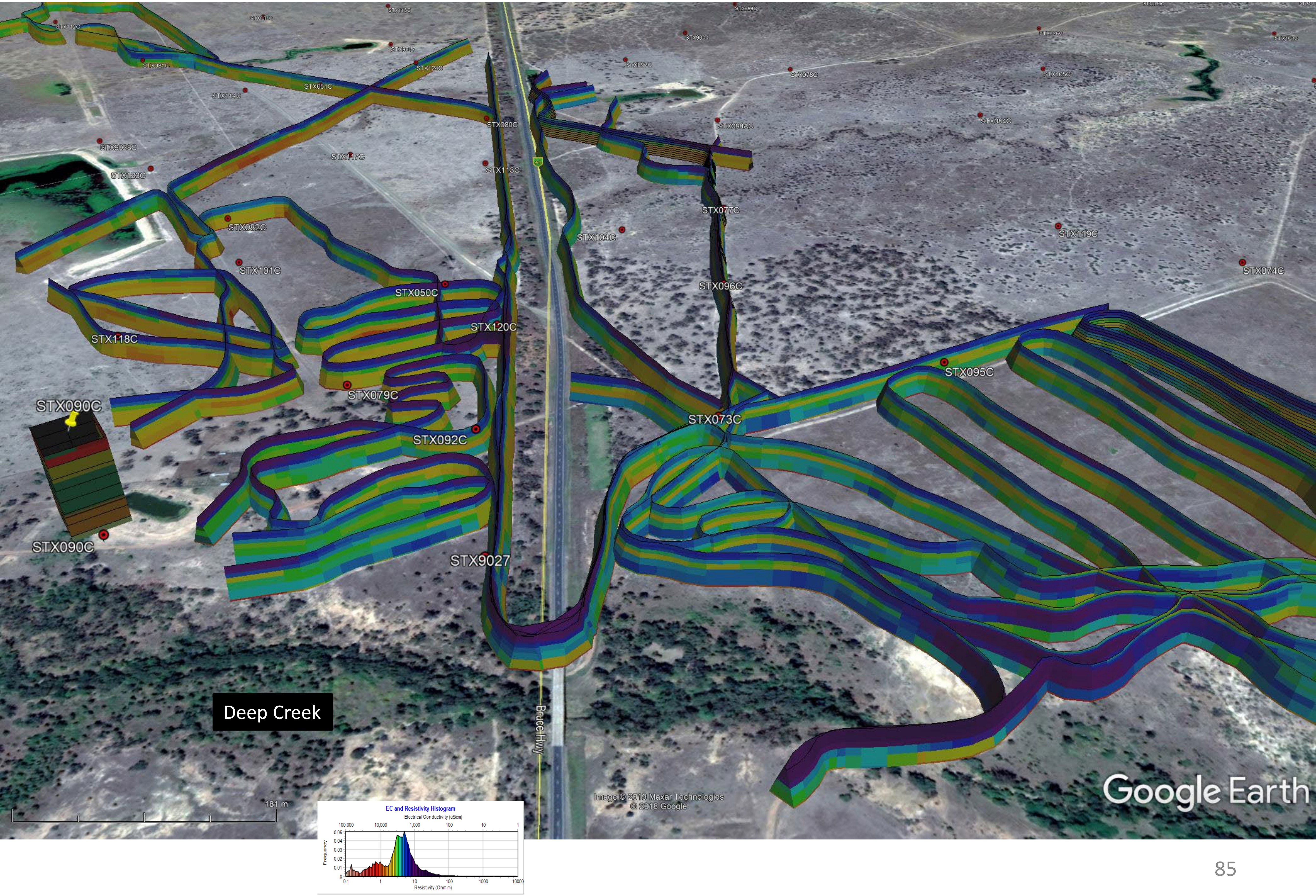
Brussels, Mamelon – looking NW – Data segment 6 of 7





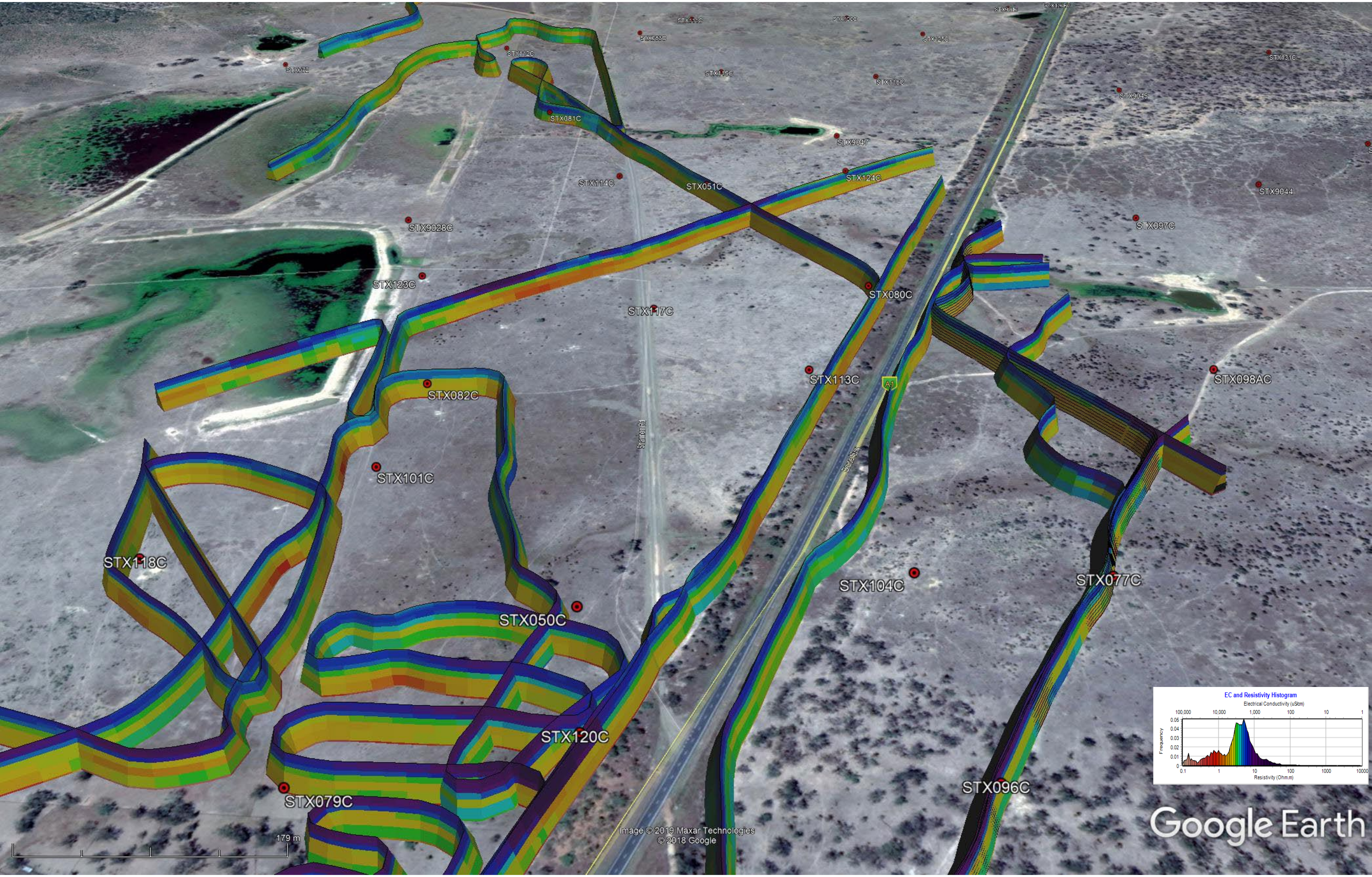
Modelled Resistivity projected up 30m

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



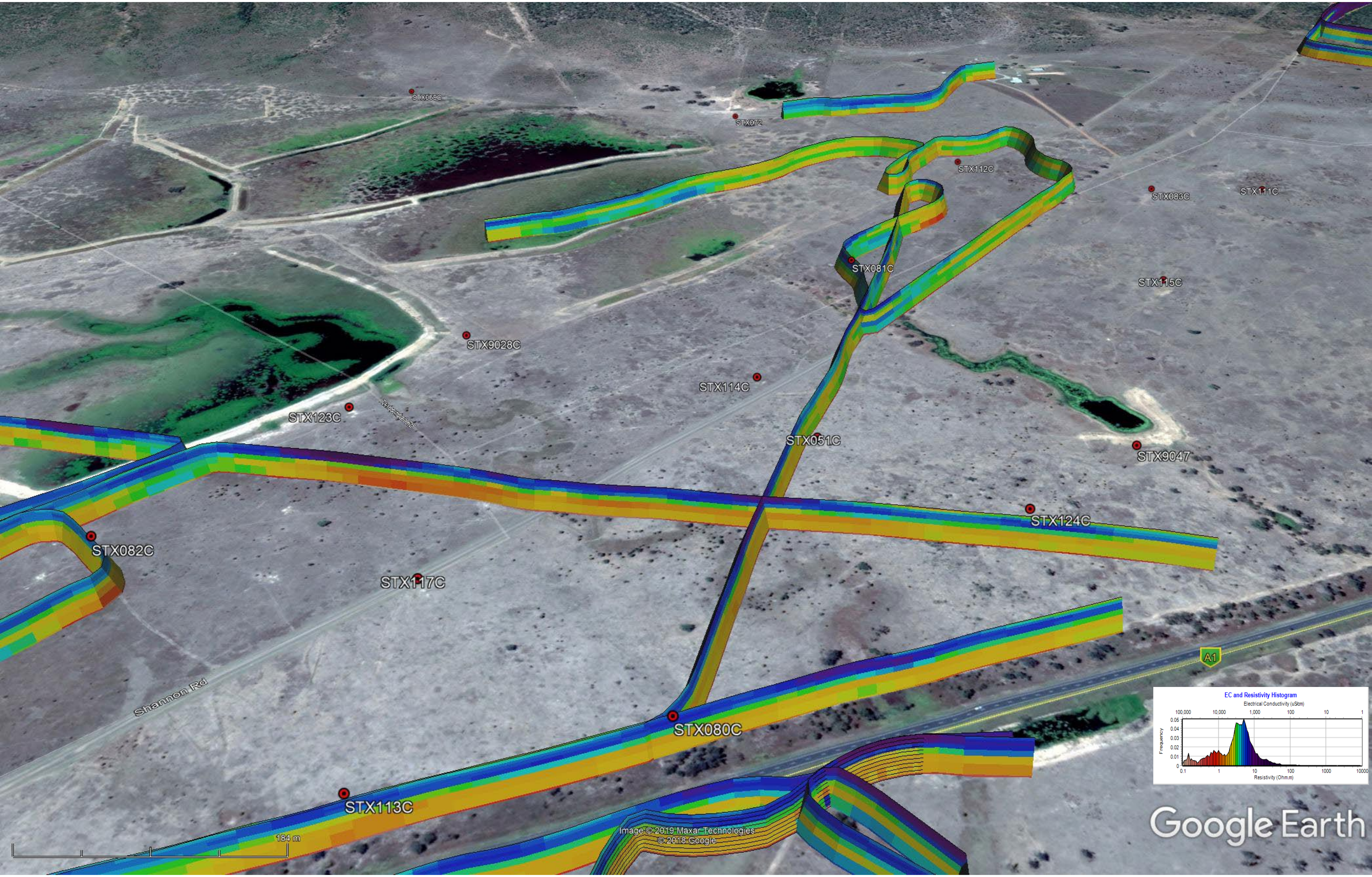
Modelled Resistivity projected up 30m

Mamelon – looking NW – Data segment 6 of 7



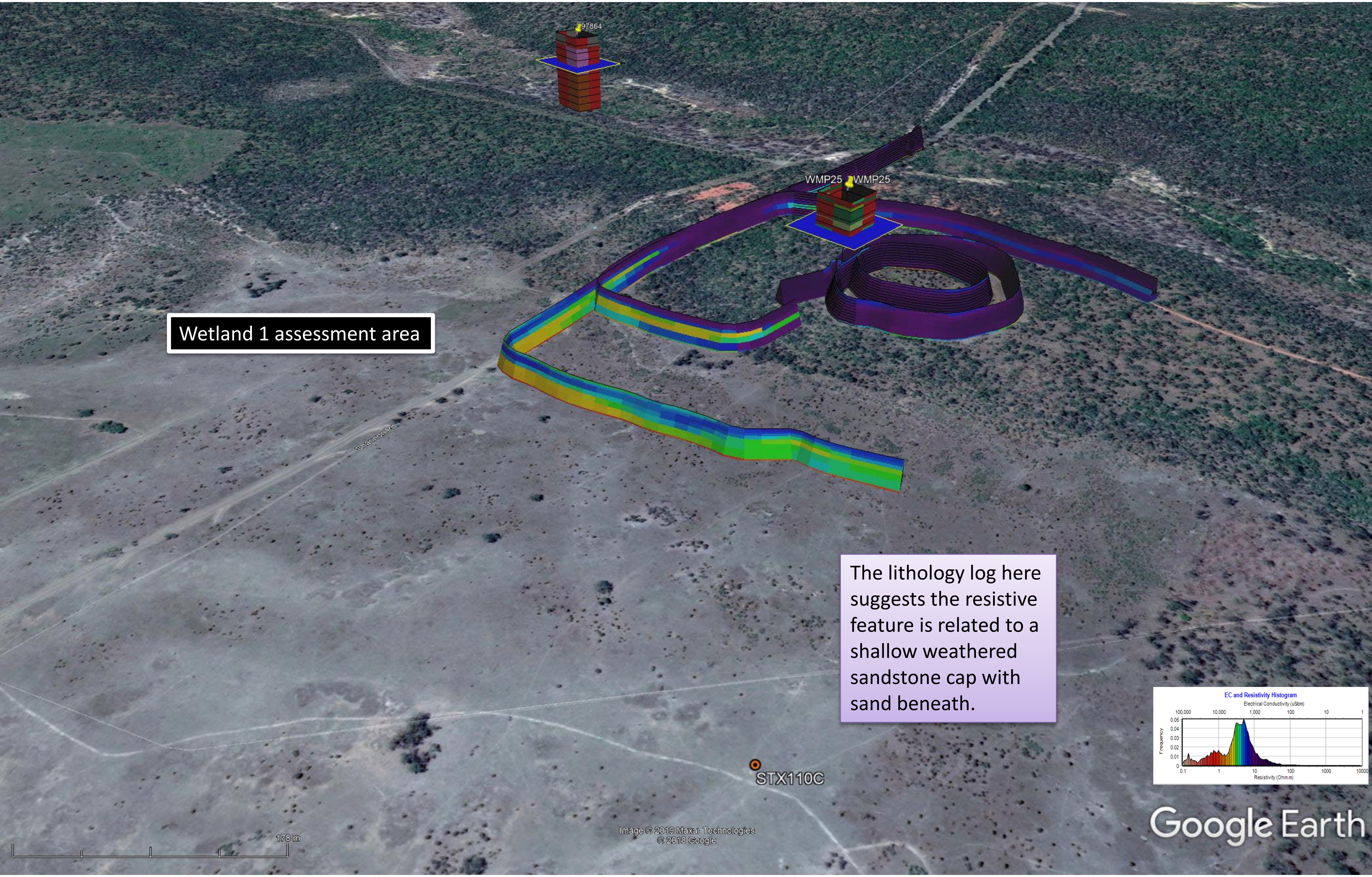
Modelled Resistivity projected up 30m

Mamelon – looking West – Data segment 6 of 7



Modelled Resistivity projected up 30m

Mamelon – looking West – Data segment 6 of 7

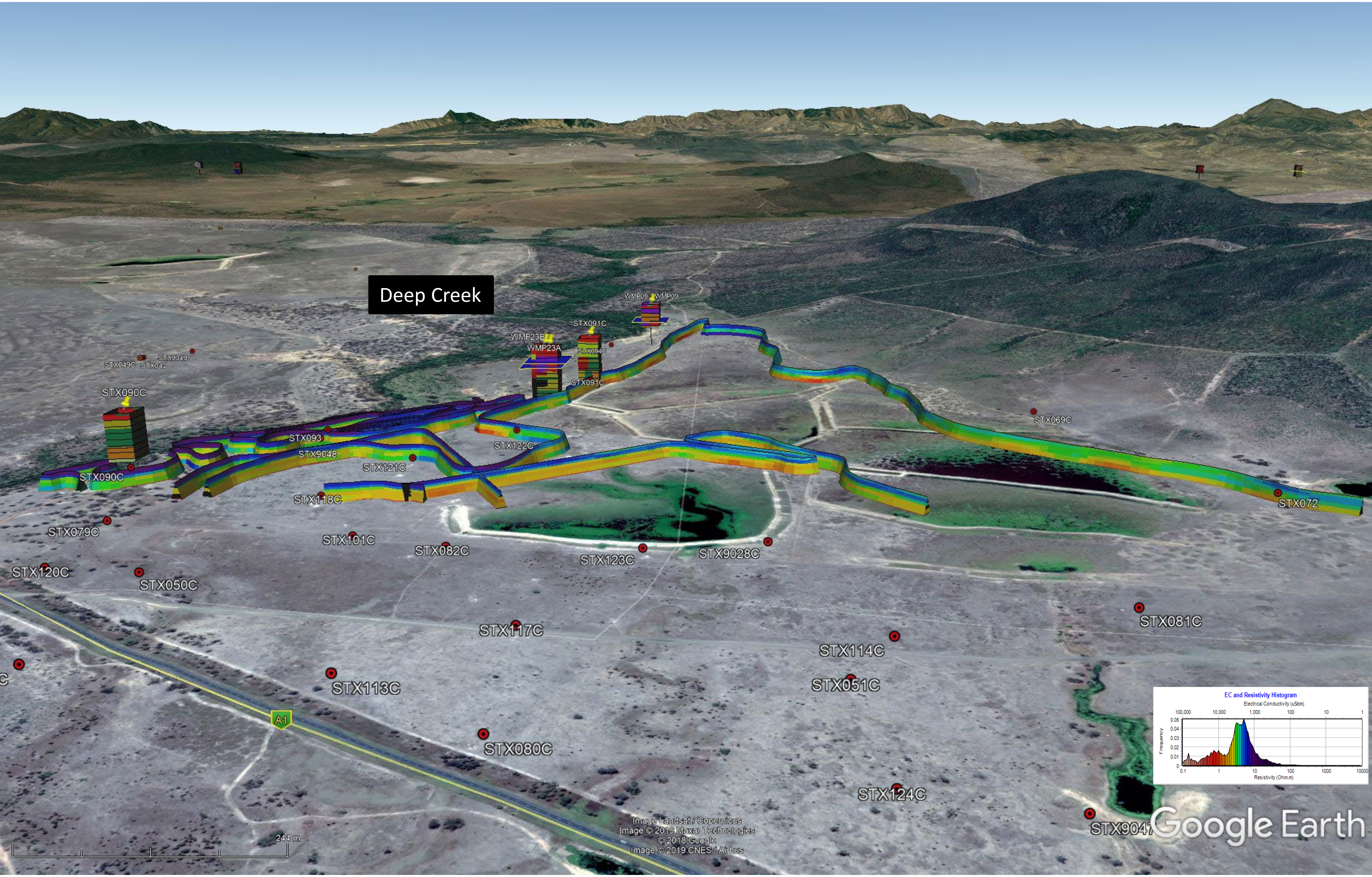


Wetland 1 assessment area

The lithology log here suggests the resistive feature is related to a shallow weathered sandstone cap with sand beneath.

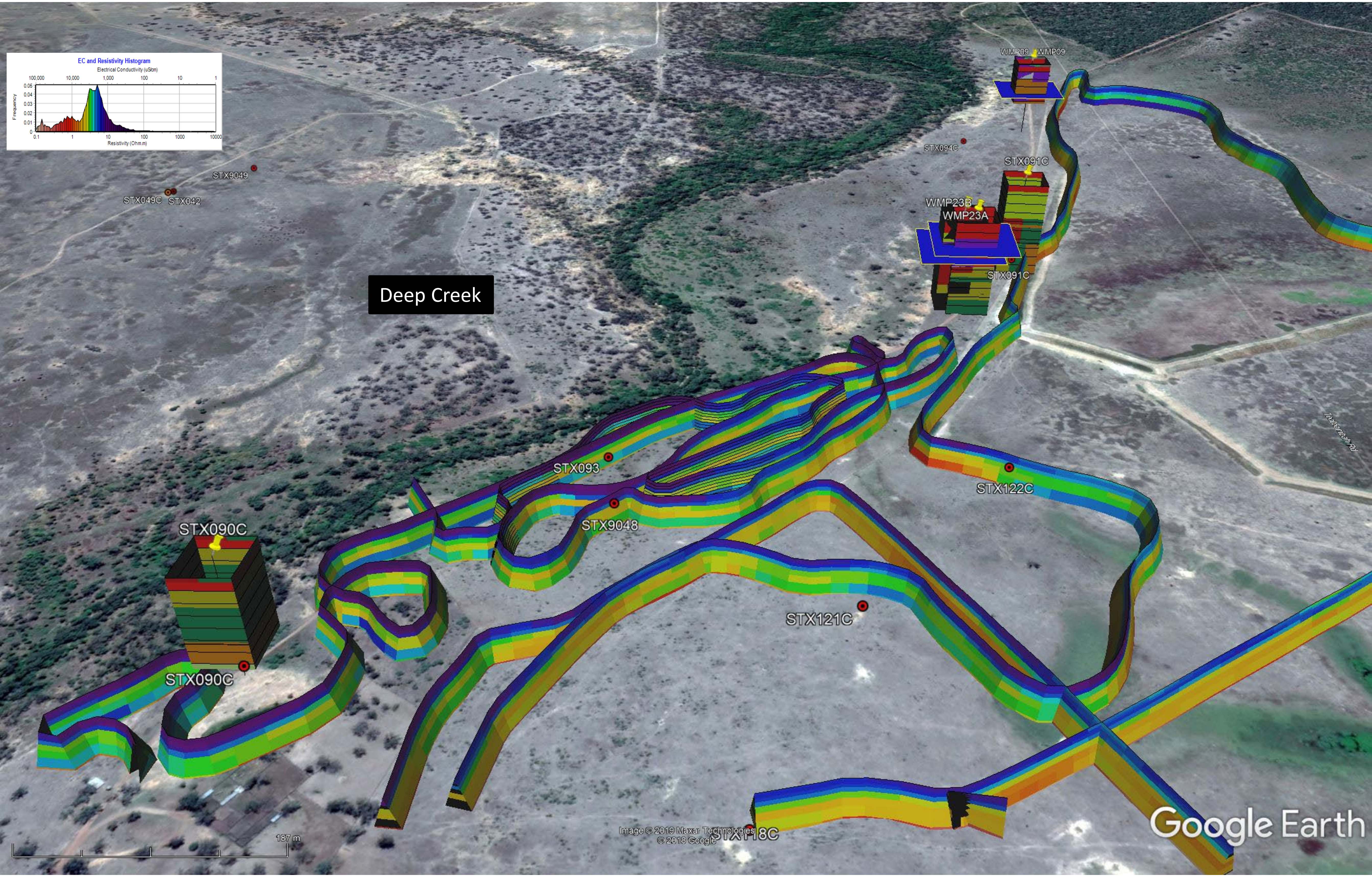
Modelled Resistivity projected up 30m

Mamelon South – looking South – Data segment 7 of 7



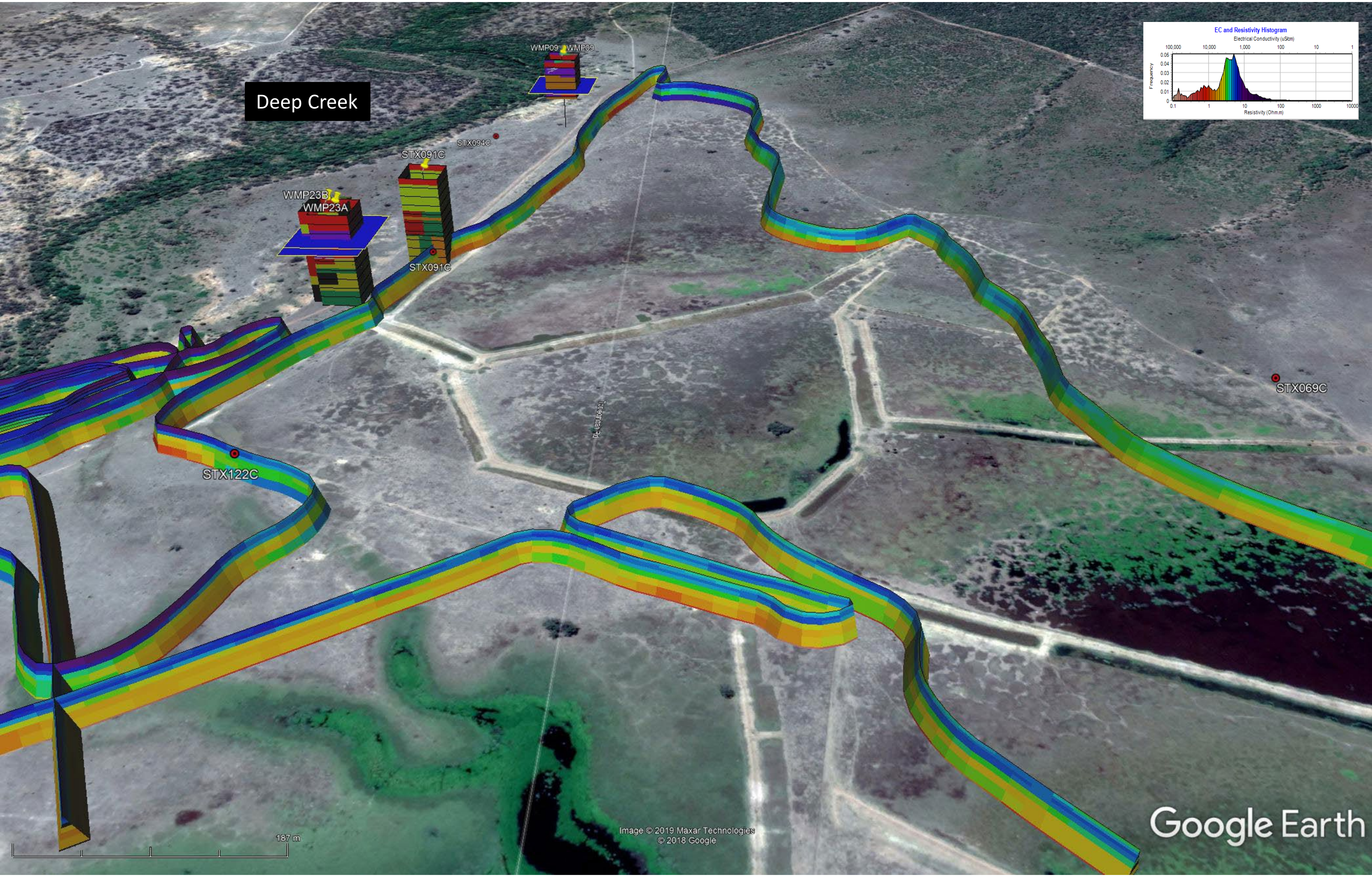
Modelled Resistivity projected up 30m

Mamelon South – looking South – Data segment 7 of 7



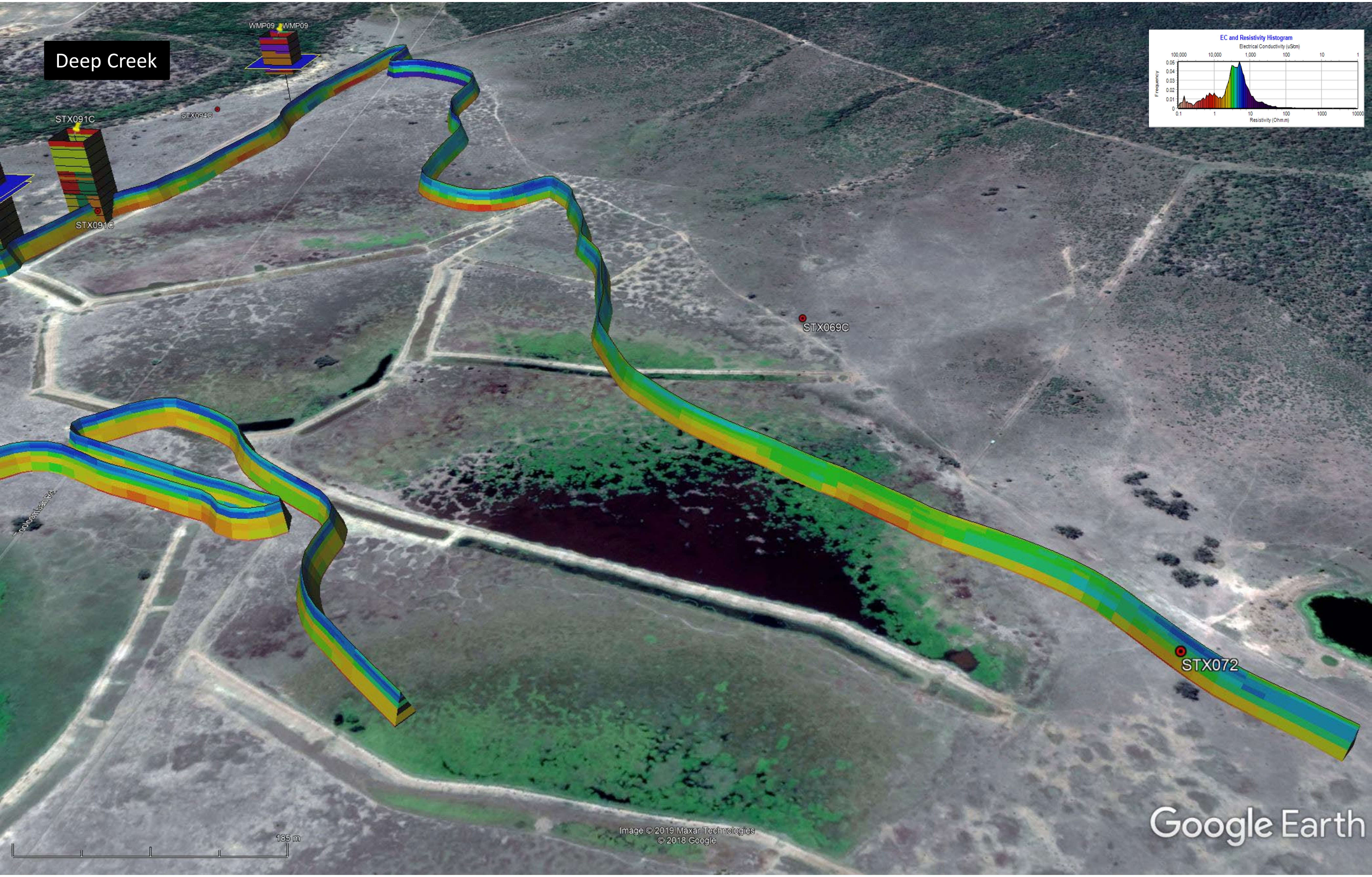
Modelled Resistivity projected up 30m

Mamelon South – looking South – Data segment 7 of 7



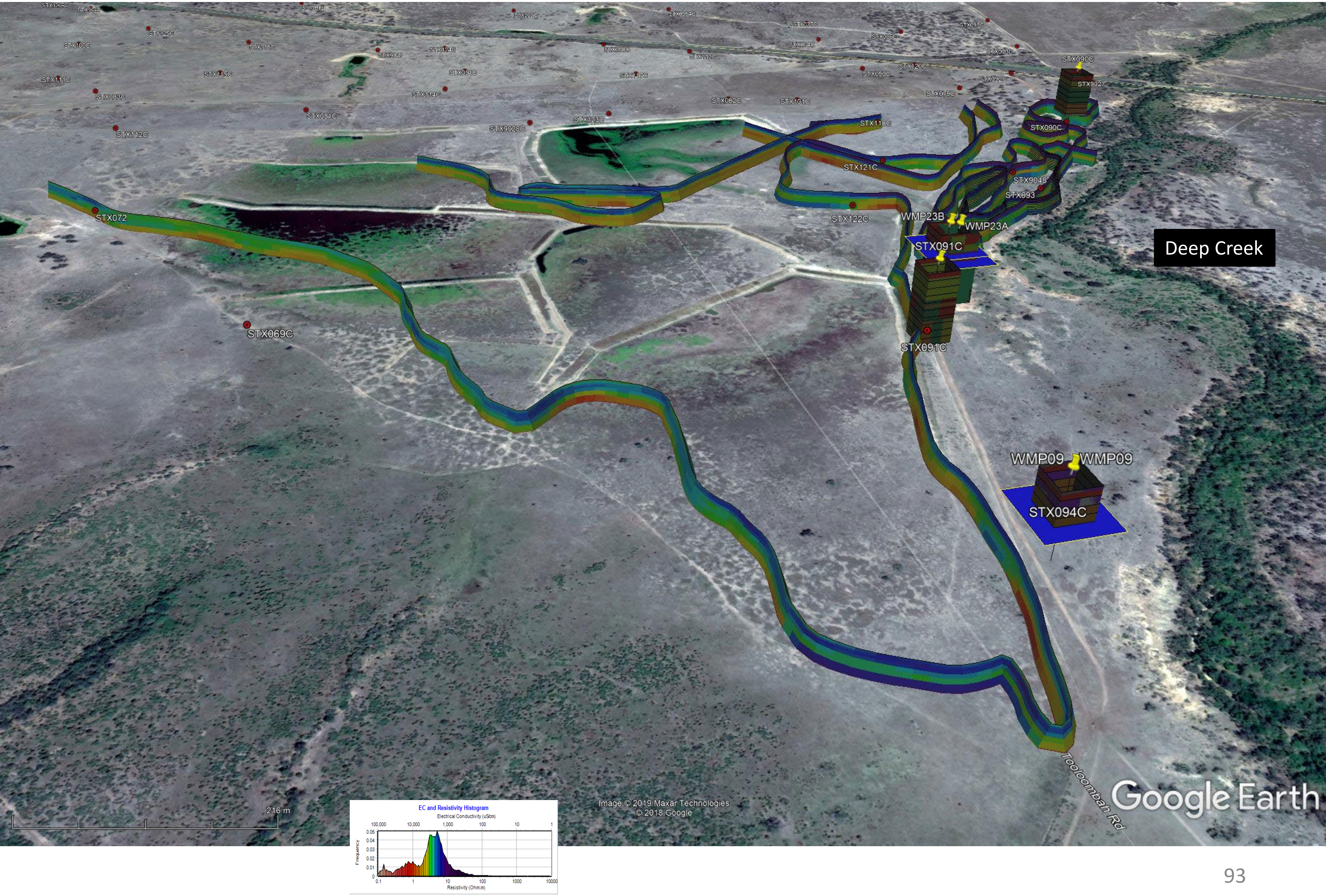
Modelled Resistivity projected up 30m

Mamelon South – looking South – Data segment 7 of 7



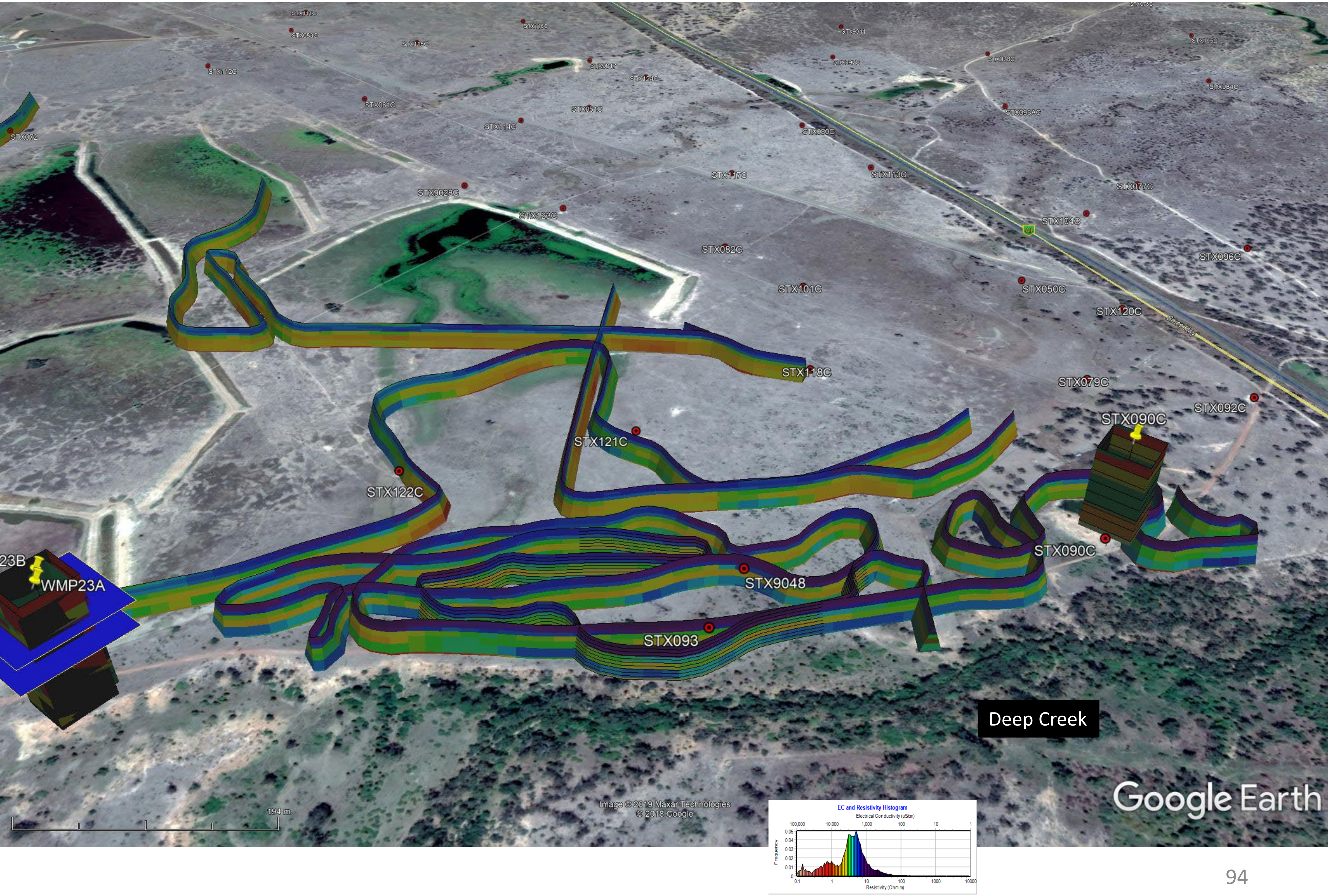
Modelled Resistivity projected up 30m

Mamelon South – looking North – Data segment 7 of 7



Modelled Resistivity projected up 30m

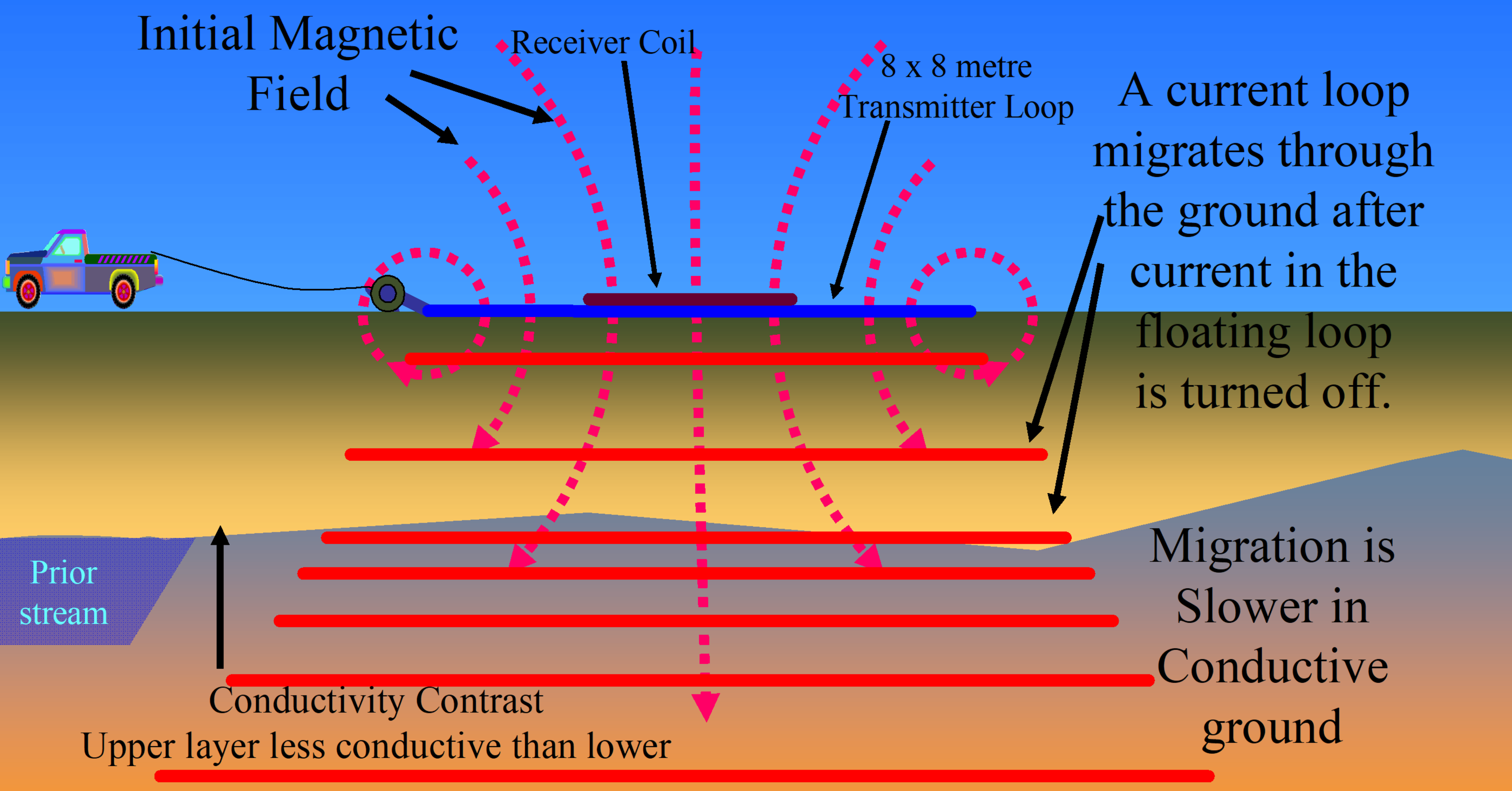
Mamelon South – looking NW – Data segment 7 of 7



Appendices

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

Towed Transient Electromagnetic System



Initial Magnetic Field

Receiver Coil

8 x 8 metre Transmitter Loop

A current loop migrates through the ground after current in the floating loop is turned off.

Prior stream

Migration is Slower in Conductive ground

Conductivity Contrast
Upper layer less conductive than lower

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.

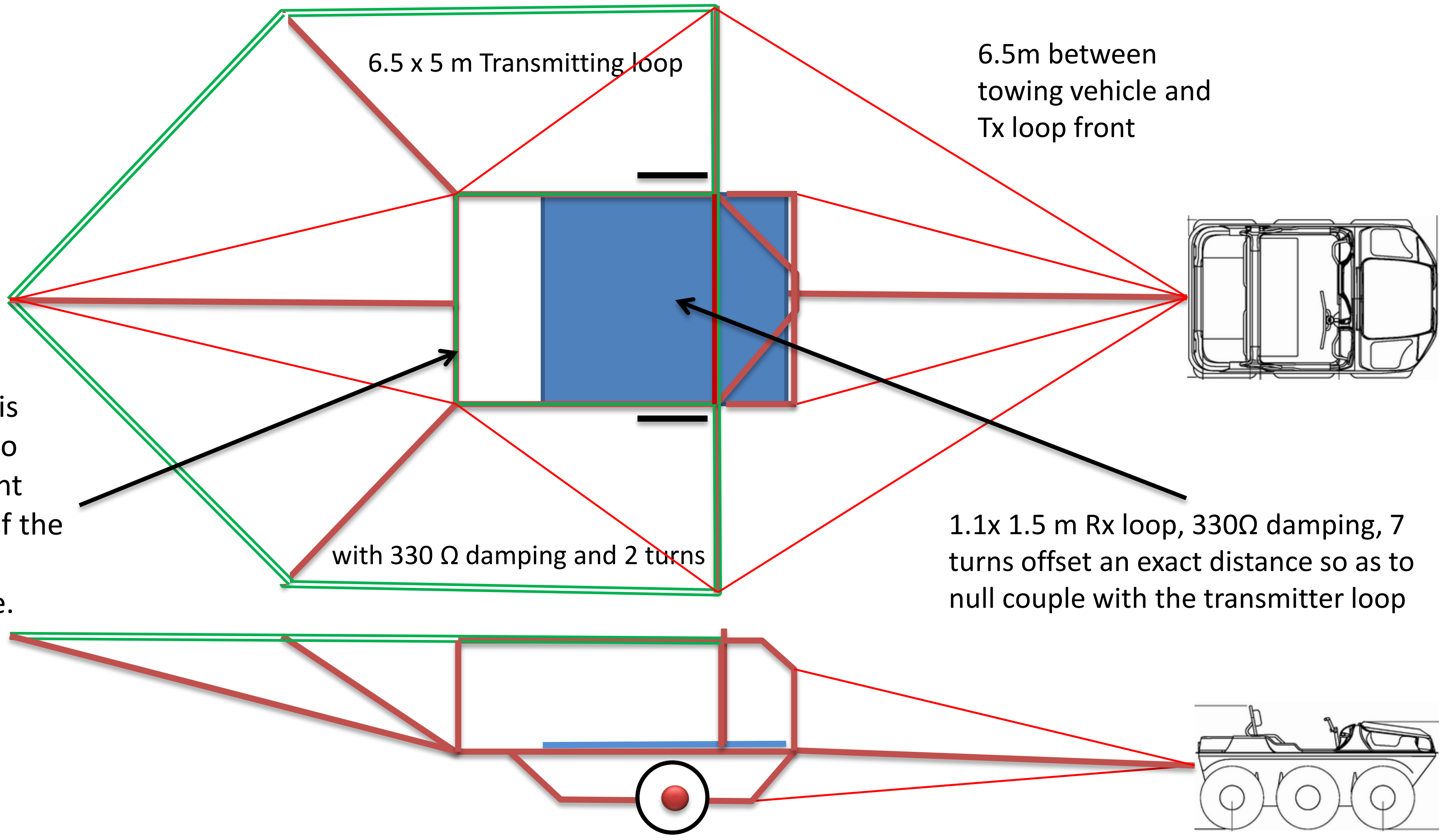
The drawbar is an arrangement of fibreglass tube and tensioned kevlar ropes.

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

6.5 x 5 m Transmitting loop

with 330 Ω damping and 2 turns

6.5m between towing vehicle and Tx loop front

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.

1.1x 1.5 m Rx loop, 330Ω damping, 7 turns offset an exact distance so as to null couple with the transmitter loop

Vertical section

Exact loop dimensions

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

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

General Processing Sequence

Define System Geometry

–

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

Transient EM equipment specifications

Alpha GeoInstruments

terraTEM

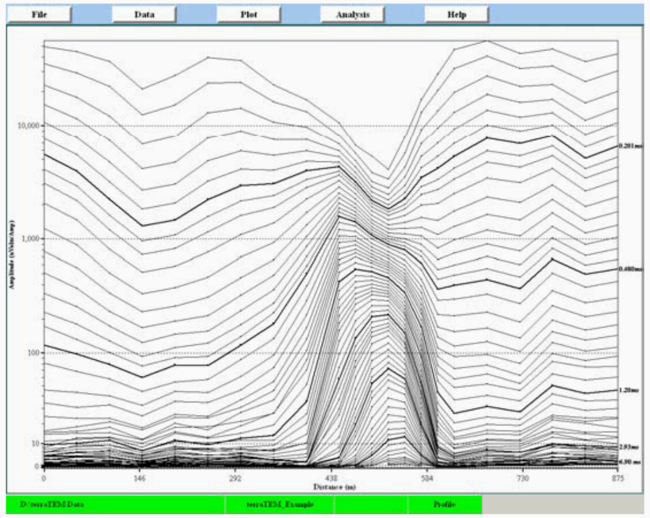
Time-Domain EM Surveying System

terraTEM Features

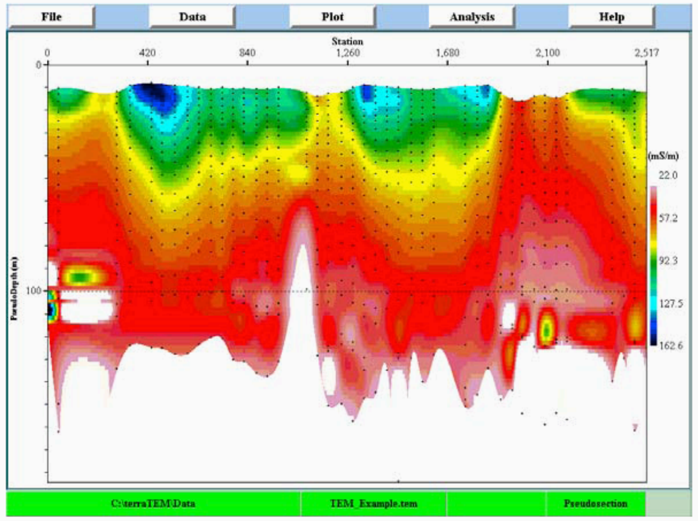
- Transmitter and receiver in one unit
- Single or 3 channel receiver with 10 amp. transmitter
- High speed sampling at 500 kHz for superior near surface resolution
- Easy to use touch screen with auto set-up and smart menus
- Large 15″ LCD display for data visualisation
- Fast and easy data transfer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

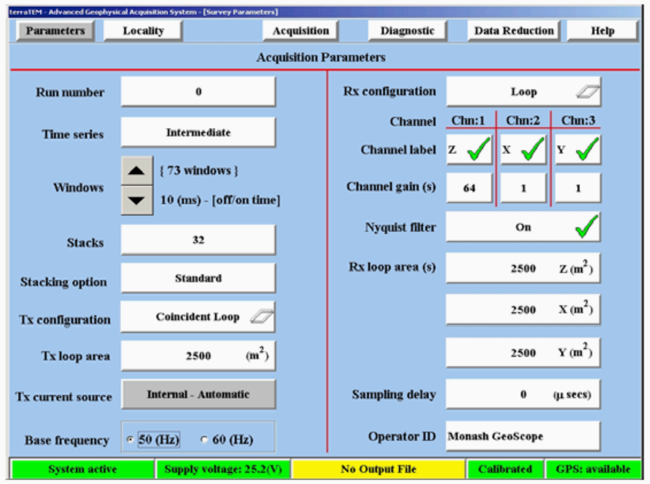
The **terraTEM** is designed, developed and manufactured by **Monash GeoScope**

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



Run number: 0
Time series: Intermediate
Windows: { 73 windows } 10 (ms) - [off/on time]
Stacks: 32
Stacking option: Standard
Tx configuration: Coincident Loop
Tx loop area: 2500 (m^2)
Tx current source: Internal - Automatic
Base frequency: ● 50 (Hz) ○ 60 (Hz)
Rx configuration: Loop
Channel: Chn:1, Chn:2, Chn:3
Channel label: Z ✓, X ✓, Y ✓
Channel gain (s): 64, 1, 1
Nyquist filter: On ✓
Rx loop area (s): 2500 Z (m^2); 2500 X (m^2); 2500 Y (m^2)
Sampling delay: 0 (μ secs)
Operator ID: Monash GeoScope
System active | Supply voltage: 25.2(V) | No Output File | Calibrated | GPS: available

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

Latitude :: 37 54.4947S
Longitude :: 145 7.8656E
Altitude :: 221.90 (m)
Positional Fix :: GPS SPS MODE; FIX AVAILABLE
UTC :: 23:4:27.999
GPS Data :: VALID
Coordinates for run :: 0
Loop: 0
Line: 0
Station: 0

PRN	7	28	26	29	24	8	9	4	11
Elevation	83	40	39	34	32	26	23	21	9
Azimuth	114	114	286	309	72	47	226	26	137
SNR	36	0	0	30	34	45	0	44	0

Status:: System Active | System power:: 23.3(V) | No Output File | Calibrated | GPS::Available

Internal GPS, for positional accuracy (option)

General Specifications

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

Further Information

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

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

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

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terraTEM
Technical Specifications

Transmitter

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

Receiver

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

Console

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

External Interfaces

Communications	USB and Serial port for data transfer

Equipment Supplied

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

Sensor Attachments Available

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

Physical

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

Options

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

Further Information

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

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

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

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

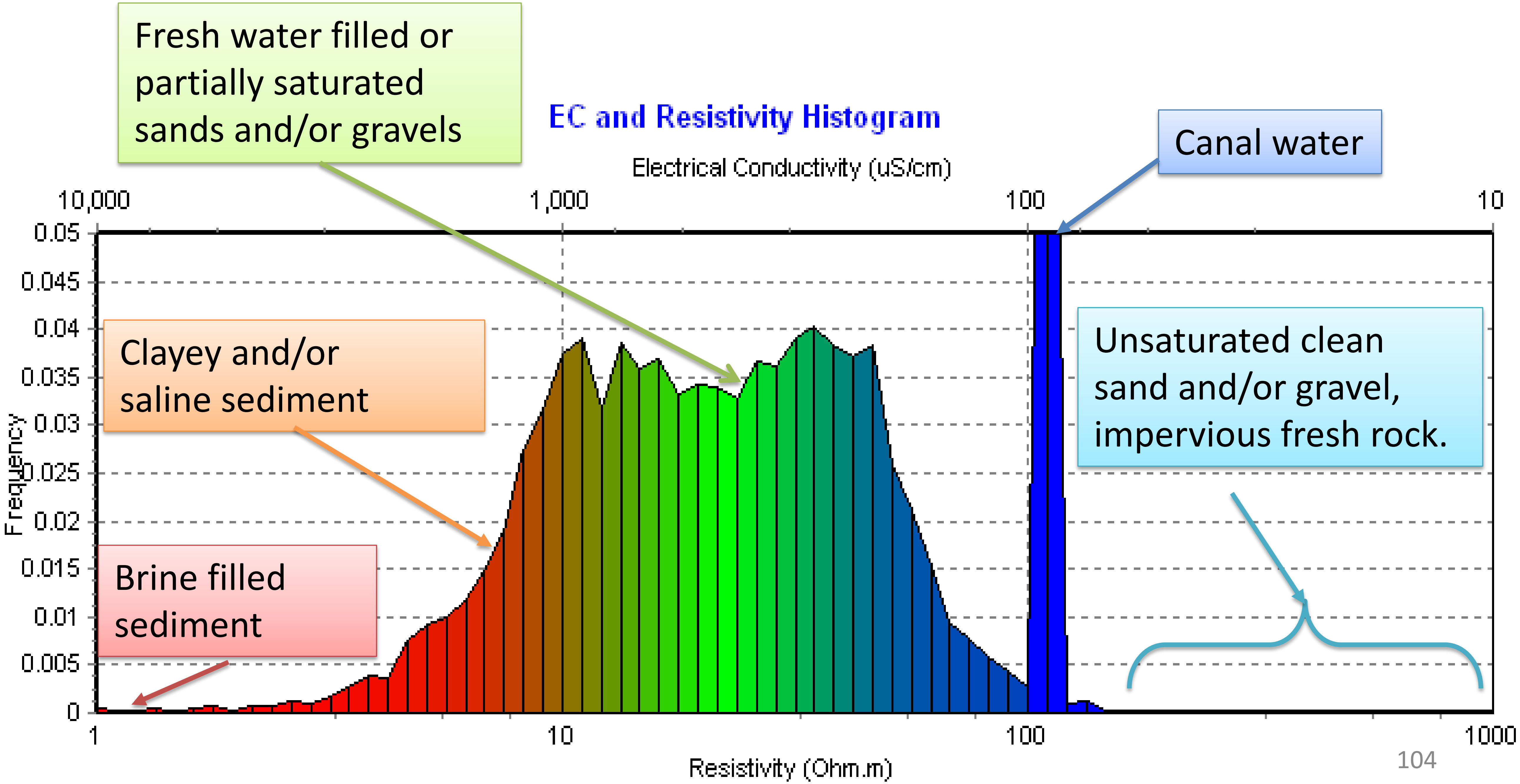
Accompanying data files in dBase IV format can be loaded in and out of MS Excel. The format has been chosen because it is easy to load into ESRI ArcView products. The final data is labelled *Ohmm.dbf and is of course in units of Ohm.m, the reciprocal of Siemens per metre. Each resistivity column is accompanied 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.



Fresh water filled or partially saturated sands and/or gravels

Canal water

Clayey and/or saline sediment

Unsaturated clean sand and/or gravel, impervious fresh rock.

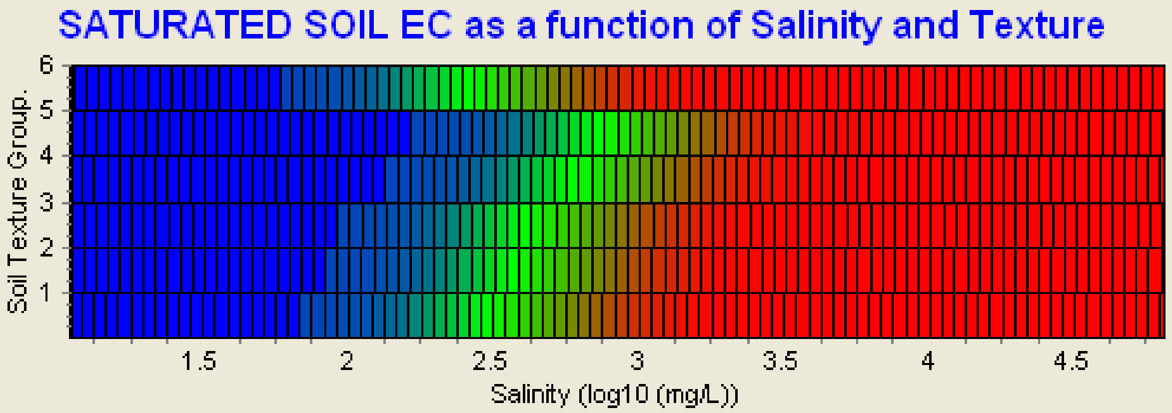
Brine filled sediment

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.



and using a Salinity conversion factor mg/L / uS/cm of 0.64.
After Slavich & Petterson - Aust J. Soil Res., 1993, 31, 73-81

Bore Lithology Graphics

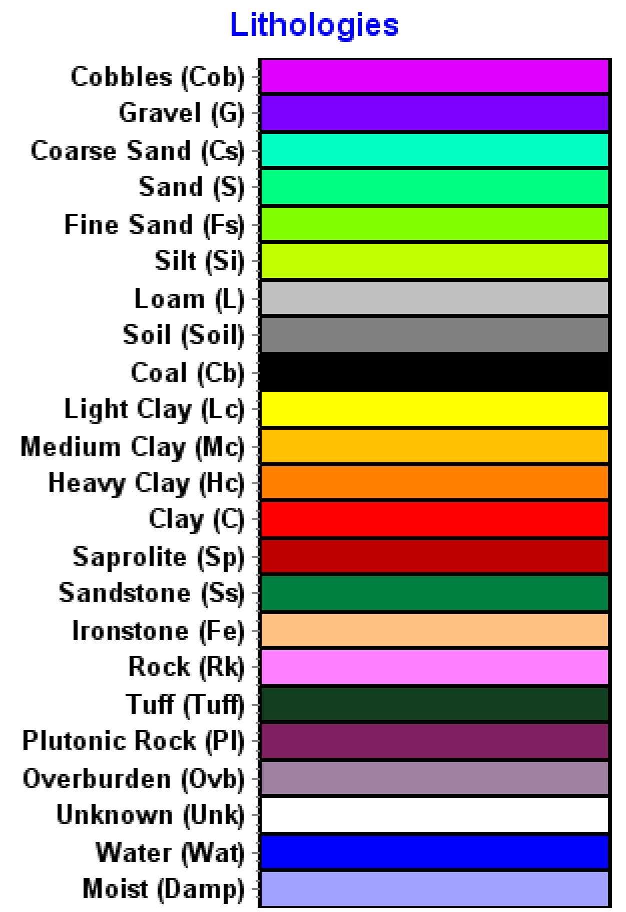
In the images, bore logs are displayed graphically using lithology keys such as the one given here.

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

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

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

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

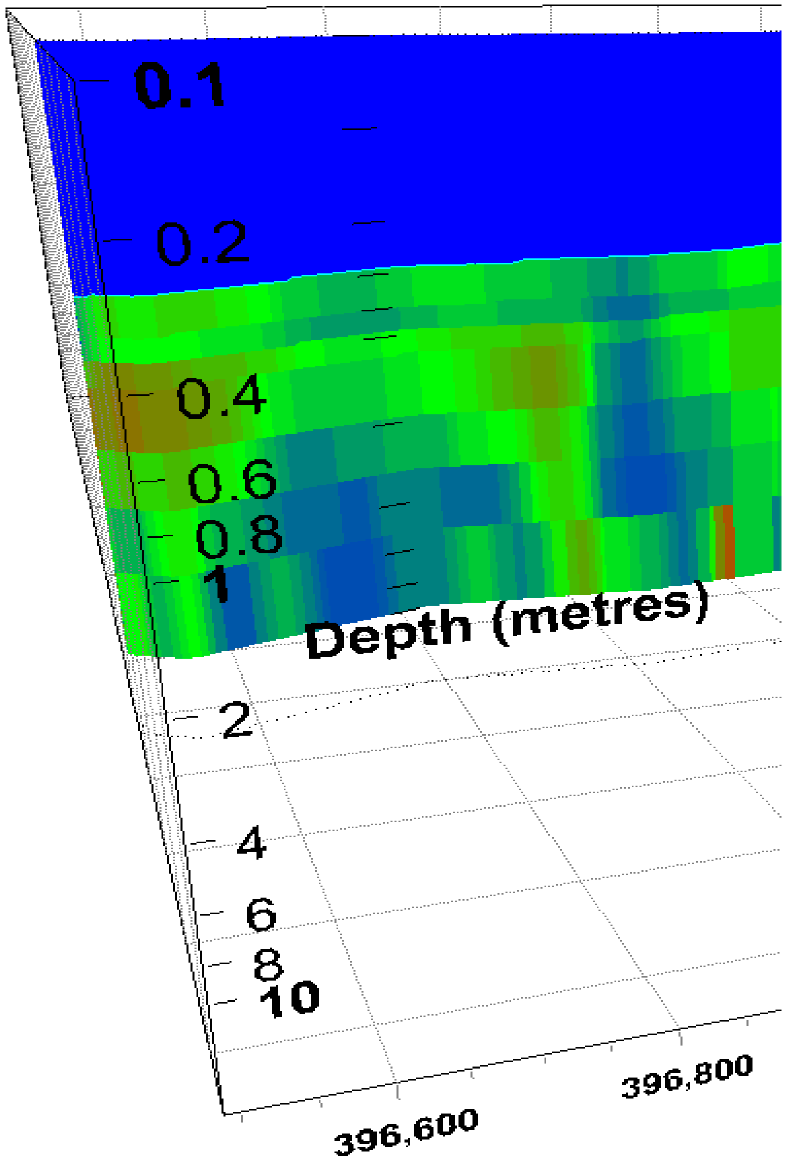


Identifying depths on ribbons

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

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

The canal bed is marked with an aqua line.



ATTACHMENT 6
FLUVIAL GEOMORPHOLOGY ASSESSMENT
(FLUVIAL SYSTEMS PTY LTD, 2020)

Central Queensland Coal Project

Environmental Impact Statement

Supplementary Study Report

Fluvial Geomorphology

Dr Christopher J Gippel

Draft

July 2020

FLUVIAL SYSTEMS

Central Queensland Coal Project

Fluvial Geomorphology

Prepared for:

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Date	18-07-2020
Prepared by	Christopher Gippel
Reviewed by	Marc Walker (Orange Environmental), Natasha McIntosh (Orange Environmental) and Aaron Hagenbach (THE HYDRO-GEOLOGie INSTITUTE)

Revision History

Revision	Revision Date	Details	Authorised	
			Name/Position	Signature
A	27-May-2020	Draft for Review	Chris Gippel Director Geomorphologist	
B	9-July-2020	Draft for Review	Chris Gippel Director Geomorphologist	
C	18-July-2020	FINAL	Chris Gippel Director Geomorphologist	

Table of Contents

GLOSSARY OF TERMS

Term	Definition
Alluvium (alluvial)	Sediment deposited distant from its source after transport by flowing water, as in a riverbed, floodplain, delta, or alluvial fan.
Bed shear stress (also Shear stress)	The force of moving water against the bed of the channel, calculated as a function of the product of slope and water flow depth. Used to indicate the likelihood that surface particles will be eroded or vegetative cover scoured.
Catchment	The area from which a surface watercourse or a groundwater system derives its water.
Cover (of riparian vegetation)	Foliar projective cover of the ground.
Discharge	A release of water from a particular source.
Drainage	Natural or artificial means for the interception and removal of surface or subsurface water.
Ecology	The study of the relationship between living things and the environment.
Ecosystem	As defined in the *Environment Protection and Biodiversity Conservation Act 1999*, an ecosystem is a ‘dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit.’
Environment	As defined within the *Environmental Planning & Assessment Act, 1979*, all aspects of the surroundings of humans, whether affecting any human as an individual or in his or her social groupings.
Fluvial	Of or found in a river.
Fragility (geomorphic)	Relative ease of adjustment of bed material, channel geometry, and channel planform when subjected to degradation or certain threatening activities (Cook and Schneider, 2006) (see also Resilience).
Geology	Science of the origin, history, and structure of the earth.
Geomorphic condition (of a stream)	Relative state of stream geomorphic characteristics relative to the state that is unimpacted by human disturbance (Fryirs, 2003).
Geomorphology	The science of the structure, origin, and development of the topographical features of the earth's surface.
Global Mapper™	A GIS application, especially suited to terrain analysis (see also Terrain analysis)
Grid (in GIS)	An array of rectangular or square cells, with a numerical attribute value for the cell stored in its centroid; often refers to elevation but can describe any attribute (see also Raster).
Gully	The deep and narrow channel form that results from incision into soil or sediment.
Habitat	The place where a species, population or ecological community lives (whether permanently, periodically or occasionally).
Headwater	A stream type found in V-shaped valleys, and located within source zones for sediment.
Hydraulic	Refers to the physical properties of flow: velocity, depth and bed shear stress.

Term	Definition
Hydrology	The study of rainfall and surface water runoff processes.
Impact	Influence or effect exerted by a project or other activity on the natural, built and community environment.
Incision	Deepening of a channel by scour (erosion) (see also Scour)
Knickpoint	A local steep fall in channel bed elevation.
Large wood	Wood fallen into streams, larger than 0.1 m diameter and more than 1 m long.
LiDAR	Light Detection and Ranging (see ACRONYMS), also known as airborne laser scanning; a remote sensing tool that is used to map ground elevation.
Long profile	A plot of elevation against distance, in this case along a stream bed.
Polygon (in GIS)	A closed shape defined by a connected sequence of x,y coordinate pairs, where the first and last coordinate pair are the same and all other pairs are unique.
Pool	A deeper section of a stream that retains water.
Proposed development	Coal mining and associated activities within the CQC Project area.
Raster (in GIS)	A spatial data model that defines space as an array of equally sized cells arranged in rows and columns, and composed of single or multiple bands (see also Grid).
Resilience (geomorphic)	Low fragility, with only minor changes likely, regardless of the level of damaging impact (Brierley et al., 2011).
Riparian	Relating to the banks of a natural watercourse.
River Styles®	A geomorphic classification based on valley setting, level of floodplain development, bed materials and reach-scale physical features within the stream (see also Stream type)
Runoff	The portion of water that drains away as surface flow.
Slope (quantified)	Also known as gradient, expressed as a ratio of integers (vertical:horizontal), the vertical gain divided by the horizontal distance (m/m), or the angle of the incline (degrees).
Stream	A general term that covers all morphological features, from small rivulets to large rivers, that perennially, intermittently or ephemerally convey concentrated water flow (see also Watercourse).
Stream link	Lengths of stream between two nodes, where a node is the beginning of a First Order stream, the junction of two streams, or some other locally defined boundary.
Stream Order	According to the Strahler system, whereby a headwater stream is Order 1, and the Order increases by 1 when a stream of a given Order meets one of the same Order.
Stream type	A geomorphic classification based on valley setting, level of floodplain development, bed materials and reach-scale physical features within the stream, consistent with River Styles® (see also River Styles®)
Surface water	Water flowing or held in streams, rivers and other wetlands in the landscape.
Terrain analysis	The automated analysis of landforms using digital elevation data sets.
Tributary	A river or stream flowing into a larger river or lake.

Term	Definition
Vector (in GIS)	A coordinate-based data model that represents geographic features as points, lines, and polygons (see Polygon).
Watercourse	Any flowing stream of water, whether natural or artificially regulated (not necessarily permanent) (see also Stream).

ACRONYMS

Acronym	Expansion
AHD	Australian Height Datum
DEM	Digital Elevation Model
EIS	Environmental Impact Statement
GIS	Geographic Information System
LiDAR	Light Detection and Ranging
ML	Mining Lease
SEIS	Supplementary Environmental Impact Statement

UNITS

Symbol	Unit
ha	Hectare
km	Kilometre
km^2	Kilometres squared
m	Metre
m^2	Metres squared, or square metres
m^3	Metres cubed, or cubic metres
mm	Millimetre
ML/d	Megalitres per day
t	Tonne

Executive Summary

This report documented the geomorphological character of the CQC Project area using repeatable methods. Characterisation of the geomorphology of the area was approached at the landscape and stream reach/point scales. Streams were classified according to Strahler Stream Order and geomorphic type, and geomorphic features of the streams were measured at the reach/point-scale.

Terrain analysis, the automated analysis of landforms using digital elevation data sets, was undertaken using a Light Detection and Ranging (LiDAR) derived Digital Elevation Model (DEM). This objective of this analysis was to classify streams according to geomorphic type, and geomorphic condition.

Most of the stream reaches were in a stable, moderate geomorphic condition. Some streams were potentially impacted by factors that reduced their condition. Riparian vegetation, although present in most places, was impaired in terms of width and continuity. One migrating bend on the Styx River, just downstream of the Ogmore Bridge, outside the Project area, was identified as a significant source of sediment to the river. No knickpoints or zones of major geomorphic instability were observed on the mapped watercourses. However, the Styx River catchment contains a significant number of alluvial gullies and small tributaries incised into old alluvium. These are potentially sources of high sediment loads to the river system, and thus the Great Barrier Reef.

The main hydrologic impact during the early stages of development (up to and including P8) would be diversion of the southern catchment area via the Northern Diversion Drain to Deep Creek, just upstream of Barrack Creek junction. Under Existing conditions, the two most western sub-catchments that drain to the mine site flow in a northeast direction and discharge to Deep Creek. Under the developed scenario, the flow from these sub-catchments would be diverted to flow northwards around the western boundary of the mine to discharge to Tooloombah Creek. The redistribution of these flows would have negligible impact on the extent of flood inundation of the floodplains of Deep Creek, Tooloombah Creek and Styx River.

The risk of erosion of the watercourses was assessed over a 2.5 m grid using the method of maximum permissible bed shear stress and maximum permissible velocity, using hydraulic data provided by the two-dimensional TUFLOW flood study model. This geomorphic assessment evaluated the 10% AEP and 1% AEP flood events for the Existing and the Developed P8 scenarios. The results of the assessment based on velocity were consistent with those based on bed shear stress. This assessment found that, for Tooloombah and Deep creeks and Styx River channels and floodplains, while there could be isolated areas subject to slightly higher risk of scour under the Developed scenario compared to the Existing scenario, the overall risk of rapid and significant geomorphic change due to the proposed mining activity was negligible. However, the assessment identified some localised areas where modelled velocity and bed shear stress values were such that specific mitigation and/or monitoring actions were recommended.

Six locations were highlighted where the velocity and/or bed shear stress values associated with the Developed P8 scenario were high enough to warrant monitoring and/or mitigation.

1. The 400 m-long area where drainage from the western sub-catchments concentrates and then discharges to Tooloombah Creek.
2. Discharge channel from Dam 1 to Deep Creek.
3. Where sub-catchments upstream of the mine discharge to the Northern Diversion Drain.
4. The Northern Diversion Drain, particularly the lower 500 m.
5. At the proposed rail bridge crossing over Deep Creek.
6. An isolated location near Dam 1 wall.

Sites 1 and 3 are risk areas for gully formation. They will require maintenance of good vegetation cover and regular monitoring of stability, plus preparation of a plan to fortify them with rock rip-rap should significant incision occur. Site 4, the lower end of the Northern Diversion Drain where it discharges to Deep Creek, will require fortification with rip-rap. Site 2 is likely to require fortification with rip-rap to eliminate the risk of formation of knickpoints that could migrate towards Dam 1 embankment. This is a risk with a high consequence. Site 5, at the proposed rail bridge crossing over Deep Creek, was predicted to experience bed scour. This risk can be managed by designing the bridge crossing in accordance with civil engineering design standards. Site 6 was an isolated area about 50 × 50 m near Dam 1 wall where confinement due to the dam wall was predicted to locally increase the water surface slope and thus the bed shear stress and velocity. Even so, provided this area remains vegetated, the risk of scour of the surface would be low.

Geomorphic monitoring should be undertaken using objective, scientifically sound methods, following a BACI (Before/After/Control/Intervention) design. Also, the monitoring should target areas where this assessment predicted the risk of geomorphic instability would be greatest. The foundation of the recommended approach to monitoring is topographic survey at targeted risk areas, repeated every year for 3 years, and then either every five years, or after every flood event exceeding the 5 yr ARI event. After each survey, a monitoring report is to be prepared that uses scientific methods to evaluate the data, including statistical analysis to test for significance of differences across a range of geomorphic variables derived from the survey data. Regular (monthly) visual inspections that involve fixed photo points and completion of standard documentation could support the less frequent survey data by potentially providing early detection of change.

Mitigation of the impacts of accelerated sediment delivery to the drainage system, and then to the Great Barrier Reef, can be achieved through vegetation management, maintaining complete vegetation cover over hillslope, river bank and floodplain surfaces. Grass provides good resistance to erosion on hillslopes and small gently sloping drainage channels, but forest, with tree, shrub and ground cover, is preferable on steep land, larger drainage channels and river banks. In general, the surface water management works should follow standard civil engineering design principles. However, this report draws particular attention to the need for fortification of the outlet from Dam 1 to Deep Creek, and the lower 500 m of the Northern Diversion Drain. This report also draws particular attention to the 400 m-long area where drainage from the western sub-catchments concentrates and then discharges to Tooloombah Creek, where sub-catchments upstream of the mine discharge to the Northern Diversion Drain, and an isolated location near Dam 1 wall, which will require maintenance of good vegetation cover in order to remain at low risk of surface scour.

The need for application of mitigation measures over the life of the mine would be triggered by unexpectedly large change in morphology identified through monitoring. The most appropriate response would need to be assessed at the time.

1.0 Introduction

1.1 Characteristics of the Central Queensland Coal Project

The Central Queensland Coal Project (the Project) will be developed and operated by Central Queensland Coal (CQC) and Fairway Coal (joint Proponents). As Central Queensland Coal is the senior proponent, Central Queensland Coal is referred to throughout this report.

The Project is located 130 km northwest of Rockhampton in the Styx Coal Basin in Central Queensland (Figure 1). The Project will involve mining a maximum combined tonnage of 10 million tonnes per annum (Mtpa) of semi-soft coking coal (SSCC) and high grade thermal coal (HGTC). The Project consists of two open cut operations. The run-of-mine (ROM) coal will ramp up to approximately 2 Mtpa during Stage 1 (2019 - 2022), where coal will be crushed, screened and washed to SSCC grade with an estimate 80% yield. Stage 2 of the Project (2023 - 2037) will include further processing of up to an additional 8 Mtpa ROM coal within another coal handling and preparation plant (CHPP) to SSCC and a HGTC plant with an estimated 95% yield. At full production, two CHPPs, one servicing Open Cut 1 and the other servicing Open Cut 2, will be in operation, with rehabilitation and mine closure activities occurring between 2036 and 2038.

Production from the Project is expected to commence in 2019 and extend for approximately 19 years until the depletion of the current reserve. The Project will be located within Mining Lease (ML) 80187 and ML 700022 which are adjacent to Mineral Development Licence (MDL) 468 and Exploration Permit for Coal (EPC) 1029, both of which are held by the Proponent.

The current version of the Supplementary Environmental Impact Statement (SEIS) is CQC (2020) Central Qld Coal Project Supplementary Impact Assessment Version 3. This supersedes CDM Smith (2017) and CDM Smith (2018a), now referred to as SEIS Version 1 and Version 2 respectively.

1.2 Scope and Objectives of this Report

This fluvial geomorphology assessment was undertaken at an advanced stage of the EIS process, with EIS, SEIS, as well as specialist assessments, already completed, and Government agency review comments received.

Government submissions from the Qld Department of Environment and Science (DES), Department of Agriculture and Fisheries (DAF) and Commonwealth Department of the Environment and Energy (DEE) were received by the Proponent on 14 June 2019, with the following items identified as relevant to the scope of this report (Table 1):

- DAF: Item 1.1.
- DES: Items 32.1, 32.39, 32.59 & 32.97.
- DEE: Items [21] & [3, 11, 21].

This fluvial geomorphology assessment will be used in conjunction with other assessments to inform and support the Government responses.

The key watercourses and drainage lines assessed in this report included:

- Tooloombah Creek;
- Deep Creek;
- Styx River; and
- other associated drainage lines within and in the immediate vicinity of the CQC Project Area.

This assessment builds upon the information available in the EIS and SEIS (CQC, 2020), and other resources, to provide a report that includes the following components:

1. **Baseline Component**: to help inform other specialist studies and provide background to address specific Government submission issues:
    a) Description of geology and sediment deposition processes in the Styx Basin, including:
        (i) (Qa) Quaternary Alluvium
        (ii) (Qpa) Pleistocene Alluvium / Cainozoic
        (iii) (Qr, Qf and Kx) Colluvium / Alluvial Fan Deposits (Holocene to Pleistocene) / Styx Coal Measures

(iv) (Qhe/s) Estuarine Deposits (Holocene)
(v) (Qhe/m) Estuarine Deposits
(vi) (Ta, Td, TQr) Tertiary Sediments

b) Description of the tidal interface, normal tidal limit, peak tidal limit, and storm tide limit to support tidal/estuarine mapping.

c) Description of Soil Landscapes and Sodicity based on desktop and field assessments in the SEIS (CQC, 2020) and the land suitability assessment by HESSE (2020).

d) Review of Base Case Flood Model / Assessment Results in the SEIS (CQC, 2020) and more recent two-dimensional hydraulic modelling of flood events undertaken by WRM Water & Environment (2020).

e) Following Commonwealth of Australia (2018, p. 19) Information Guidelines for Proponents Preparing Coal Seam Gas and Large Coal Mining Development Proposals, as part of the checklist of specific information needs under surface water, "*Describe the hydrological regime of all watercourses…including geomorphology, including drainage patterns, sediment regime and floodplain features*" and following Doody et al. (2019, p. 37) Information Guidelines Explanatory Note: Assessing Groundwater-Dependent Ecosystems, among the criteria to be used to assess ecosystem value "*Diversity of species, habitats, ecological processes and abiotic features such as geomorphology*". The characterisation of fluvial geomorphology of the CQC Project area includes the following:

- Fluvial geomorphological features, including, but not limited to:
    - channels, incision, aggradation, knickpoints, pools, bedrock features, hydraulic controls, riffles, bed material, dimensions and profiles, riparian zones, alluvium and gullies.
- Measured and derived geomorphic and related attributes, including, but not limited to:
    - Strahler Stream Order
    - in-channel fluvial features;
    - riparian zone vegetation structure and cover;
    - observed rate of geomorphic change; and
    - geomorphic type, condition and fragility classification

2. **Impact Assessment Component**: to help address specific Government submission issues:

a) Discuss the potential increased risk of stream bed and bank erosion based on the identified stream geomorphic type and geomorphic features and attributes, together with the results of modelling of flood hydraulics and also considering historical rates of geomorphic change.

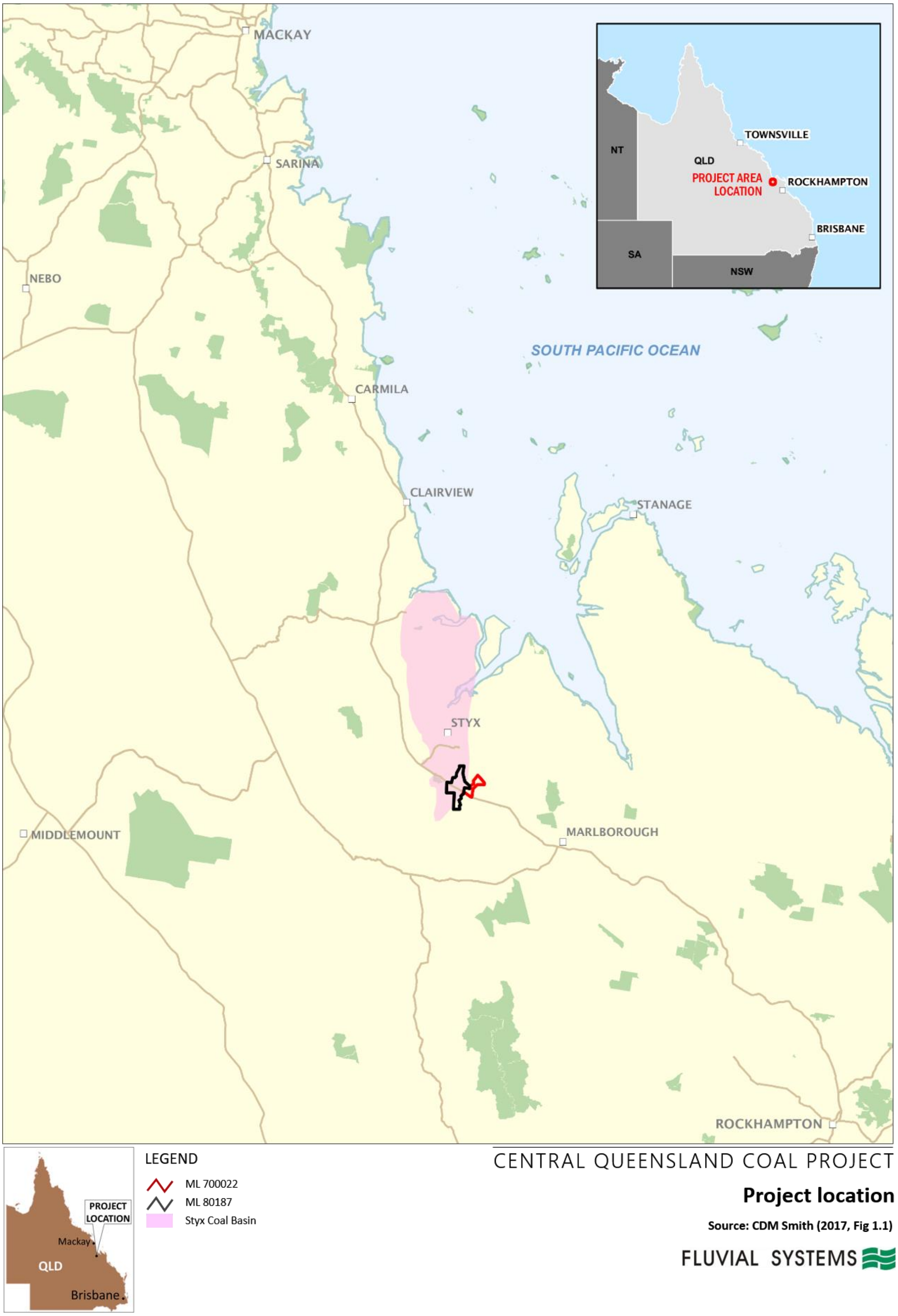
b) Discuss the potential sodicity of waste rock and relevant management measures in the SEIS (CQC, 2020)

c) Comment and compare potential sediment loads to that presented in the SEIS (CQC, 2020)

3. **Recommended Mitigation Measures and Monitoring**

a) Recommend measures that would mitigate any identified risks of geomorphic impact.

b) Identify target sites to monitor relevant geomorphologic processes throughout the life of the proposed project and beyond.



Source: CDM Smith (2017, Fig 1.1)

Figure 1. Central Queensland Coal Project regional location.

Table 1 Summary of government submissions considered relevant to the scope of this report.

Number	Issue	Required action	Relevance
DAF: Item 1.1	The drop in base flows to Tooloombah Creek and Deep Creek will cause the loss of permanent and ephemeral pools. This loss will reduce the fisheries resources in the vicinity of the project. It is uncertain if supplementary water inputs would be sufficient to maintain this system and if this mechanism is able to be continued until the mines impacts cease. The impacts of the reduction in base flows in the estuarine areas connected to these systems has not been quantified.	The drawdown causing the mobilisation of the groundwater-saltwater interface is of particular concern as it can potentially negatively impact large areas of brackish and freshwater fish habitats as well as the Broad Sound Declare Fish Habitat Area. This impact is likely to be expressed to the greatest extent, a decade or more post the closure of the mine. Once such a delayed impact manifests how can it be halted?	The results of this geomorphic assessment will inform the (separate) groundwater assessment
DES: 32.1	Additional information regarding GDEs and water supply is still required to address the supplementary environmental flows mitigation measure.	A longer term understanding of alluvium and Styx Coal measure overburden groundwater levels is required to understand groundwater interactions. The report indicates that this will be collected.	This assessment will inform the (separate) groundwater assessment.
DES: 32.39	Sediment and erosion. Section 9.10.2 discussed potential increases in water velocities for sections of the stream downstream of the mine site. There is a need to assess and discuss the potential increased risk of stream bed and bank erosion and potential impacts to aquatic fauna as a result of bed mobilisation. The sediment loads exported to the Great Barrier Reef (GBR) world heritage area need to be assessed and minimised and adequate monitoring is necessary. Chapter 9 does not describe potential impacts to water quality and aquatic ecosystem health from the potential increased risk of stream bed and bank erosion.	Address this issue and provide load estimation analysis especially as it relates to downstream impacts. A Receiving Environment Monitoring Program (REMP) must include a monitoring program for sediment load and particle size distribution to assess impacts from stream bed/bank erosion and sediment mobilisation. Findings from sediment monitoring must also be considered in the Water Management Plan and Erosion and Sediment Control Plan annual revision.	Erosion and sediment processes will be re-assessed. Estimation of sediment load from the site is the subject of a separate assessment.
DES: 32.59	It is not clear as to whether these are the same drainage diversions referred to in Section 11.3.3.2.	Clarify whether the diversions mentioned in Table 11 -15, under the Waste rock stockpile and Water infrastructure domains are the same drainage diversions which are mentioned in Section 11.3.3.2.	Consider geomorphic implications of drainage diversions.
DES: 32.97	The proponent has not specifically addressed the potential impacts to potential refugia and nursery areas for aquatic species in any of the chapters identified in their response. Further work is required in relation to the impacts of groundwater baseflow reduction along the reaches of affected watercourses.	Baseline and Groundwater Dependent Ecosystem (GDE) studies (including mitigation and management measures) will be a requirement in any approval… A Draft GDE Monitoring and Management Plan (GDEMMP) should be submitted for assessment by the department as part of the EIS material.	This assessment will inform the (separate) groundwater assessment
DEE: Items [21]	The Department has a low degree of confidence in the ability of the current groundwater model to adequately predict the likely direct and indirect impacts on MNES, both within the project site and downstream of the project	Based on the information in the AEIS, the Department considers the proponent has not adequately responded to submission 21 site.	This assessment will inform the (separate) groundwater assessment
DEE: Items [3, 11, 21]	Due to the Department’s low confidence in the groundwater model predictions, the Department considers the AEIS does not provide an adequate assessment of potential groundwater drawdown impacts on riparian vegetation, surface water-groundwater connectivity, aquatic ecosystems (particularly waterholes), stygofauna, wetlands and surface water quality. There is the potential that the magnitude and spatial extent of groundwater drawdown has been underestimated.	Based on the information in the AEIS, the Department considers the proponent has not adequately responded to submission 3, 11 and 21 site. The relevance of this is the results of this geomorphic assessment inform the groundwater modelling.	This assessment will inform the (separate) groundwater assessment

1.3 Relevant Policy and Legislative Requirements

This report addresses part of the environmental objectives to be met under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) and Queensland Environmental Protection Act 1994 (EP Act).

This report was prepared in consideration of the checklist of specific information needs under surface water in *Information Guidelines for Proponents Preparing Coal Seam Gas and Large Coal Mining Development Proposals* (Commonwealth of Australia, 2018, p. 19), which included "*Describe the hydrological regime of all watercourses…including geomorphology, including drainage patterns, sediment regime and floodplain features*", and in consideration of criteria to be used to assess ecosystem value in *Information Guidelines Explanatory Note: Assessing Groundwater-Dependent Ecosystems* (Doody et al. (2019, p. 37), which included "*Diversity of species, habitats, ecological processes and abiotic features such as geomorphology*".

This report was prepared in consideration of government submissions from the Qld Department of Environment and Science (DES), Department of Agriculture and Fisheries (DAF) and Commonwealth Department of the Environment and Energy (DEE) received by the Proponent on 14 June 2019.

There is no legislative or policy requirement regarding the methodologies to be applied in undertaking geomorphological investigations for the purpose of an EIS. The methodologies employed in this report followed current best practice.

1.4 Report Structure

This report is structured as follows:

Section 1	Introduction – outlines the Project and presents the purpose of this report
Section 2	Methodology – describes the methodology used in this assessment
Section 3	Existing environment – describes the character of the existing geomorphologic environment
Section 4	Impact assessment – describes the potential impacts to geomorphologic character of the environment resulting from the proposed Project
Section 5	Monitoring and Mitigation – provides a summary of environmental mitigation, management and monitoring responsibilities in relation to management of geomorphologic aspects of the environment for the Project
Section 6	Conclusion – states the main conclusions arising from this assessment
Section 7	References – lists details of cited references

2.0 Methodology

2.1 Study Area

The area of interest of this report varied depending on the issue under assessment. At the broadest scale it included the entire catchment of the Styx River down to the estuary, while at the finest scale it included the zone within, and immediately adjacent to (i.e. potentially directly influenced by), the area covered by ML 80187 and ML 700022 where mining activities are proposed to be conducted (referred to as the CQC Project area) (Figure 2).

Where maps in this report depict geomorphologically-relevant attributes extending outside the CQC Project area, the purpose was to show the continuity of the attribute being described, and/or to illustrate the regional context of the attribute.

2.2 Measurement Scales

Characterisation of the geomorphology of the area of interest was approached at two measurement scales:

1. Landscape, which covers geomorphological or geomorphologically-relevant characteristics such as landform terrain attributes and soil attributes at the regional and catchment scale.
2. Stream reach- and point-scale, which covers physical attributes of streams of the CQC Project area at the cross-section- and reach-scale (1 to 1,000 metres), plus the scale of stream type which varies from 10s to 1,000s of metres long.

An approach, based on standard methods, was devised to classify streams according to geomorphic type, and to measure the geomorphic features of the streams at the cross-section and reach-scale. This report provides sufficient technical information such that the methodology could be repeated at a later time by a third party. Also, the primary and secondary data from the work were provided in sufficient detail to allow a comparison of future geomorphological character with baseline (current) geomorphological character.

Characterisation of fluvial geomorphological features was based on a combination of desktop analysis of existing data and previously collected field data.

2.3 Data Sources

2.3.1 Primary data

It was not possible to undertake a field inspection of the site due to government restrictions that applied at the time of preparation of this report. This did not pose a significant limitation to this report, because: i) the methodology made use of existing spatial data layers, aerial imagery and topographic data, ii) extensive field assessment had previously been undertaken for the EIS and Supplementary EIS, iii) ground photographs previously obtained by WRM Water & Environment in connection with recent flood hydraulic modelling were made available, and iv) CQC staff obtained ground photographs taken at specific locations on request.

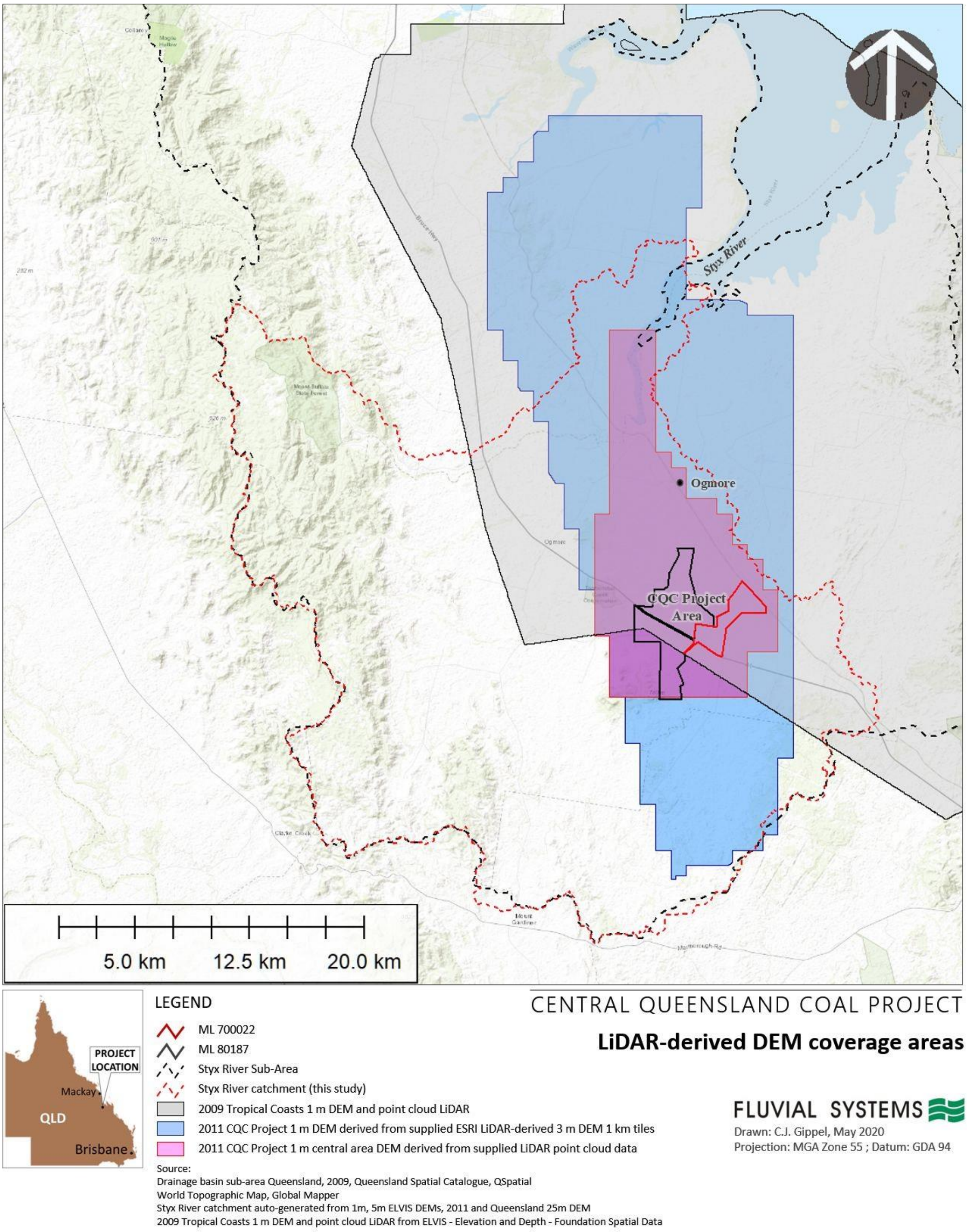
2.3.2 Elevation data

This geomorphic investigation relied on digital elevation model (DEM) data, derived from Light Detection and Ranging (LiDAR), also known as Airborne Laser Scanning (ALS), surveys flown at a range of scales and collection dates (Figure 2):

- LiDAR survey data captured in 2011 by Vekta on behalf of Yeats Consulting Engineers (Vekta, 2011), covering Exploratory Permit for Coal (EPC) 1029 on land on associated with the CQC Project, and within which ML 80187 and ML 700022 are located, available as LiDAR point clouds and 1 m and 3 m DEM tiles derived from the point cloud data,
- LiDAR survey data captured in 2009 for the Tropical Coast Project over sections of the Queensland coast from Cairns Regional Council (within the current Douglas Shire) to Rockhampton Regional Council (within the current Livingstone Shire), available as LiDAR point clouds or 1 m DEM tiles derived from the point cloud data,
- Digital Elevation Model (DEM) 5 Metre Grid of Australia (Geoscience Australia), derived from the 2009 Tropical Coast Project LiDAR in this area, and

- Digital elevation model – 25 metre – Fitzroy River catchment (Department of Natural Resources, Mines and Energy), derived from contours and drainage (scanned repromats) from AUSLIG 1:100000 mapsheets with a 20 metre contour interval for most areas.

The 5 m and 25 m products were used in this report only to depict the topography of the wider Styx River catchment, with the 2009 and 2011 products used for detailed terrain analysis.



Source:
Drainage basin sub-area Queensland, 2009, Queensland Spatial Catalogue, QSpatial
World Topographic Map, Global Mapper
Styx River catchment auto-generated from 1m, 5m ELVIS DEMs, 2011 and Queensland 25m DEM
2009 Tropical Coasts 1 m DEM and point cloud LiDAR from ELVIS - Elevation and Depth - Foundation Spatial Data

Figure 2. LiDAR data availability for the area of interest. A 25 m DEM was available for the entire area.

The Tropical Coast Project data were downloaded from ELVIS – Elevation and Depth – Foundation Spatial Data, Version 0.1.1.0 (http://elevation.fsdf.org.au/). The associated metadata indicated that the data for most of the project area were collected between 28 August 2009 and 21 October 2009. Data were collected from a fixed wing aircraft at an altitude of 1340 – 2070 m, using a Leica ALS50, with average point specification of 1 point per square metre. Ground filtering algorithms were applied to the full dataset. The ground filtered dataset was then visually checked by an operator, and incorrectly classified data was corrected or the ground filtering algorithm was adjusted and then visually checked. The accuracy of the final product was quoted as +/- 0.15 m at 67% CI in the vertical, and +/- 0.3 m at 67% CI in the horizontal.

Vekta (2011) undertook a LiDAR survey over the Styx Coal Mine area, north of Rockhampton on 17 June 2011. Data were collected from a fixed wing aircraft using a Leica ALS60, with average point specification of 1 point per square metre. Laser strikes were classified into ground and non-ground points using a single algorithm across the project area. Auto-classification was followed by manual checking and editing to remove obvious errors. Related field survey was performed on 7 June 2011. The GPS base data for the processing of the airborne LiDAR data was obtained from a base station located at permanent survey mark PSM133415 situated at Ogmore. This mark was used as the datum mark for the airborne LiDAR survey and all ground survey checks. During the flight, GPS data was logged at 0.5 second epochs from the base station. This data was used in the GPS processing of the LiDAR data. Vekta surveyors also performed a number of detail surveys evenly distributed throughout the project area to validate the accuracy of the final surface model. GPS accuracies were tested across all sections and found to be within tolerance. The accuracy of the final product was quoted as +/- 0.15 m in vertical and +/- 0.45 m in horizontal (1 sigma) in areas of clear and open terrain. An independent survey of borehole locations was supplied by surveyor Dave Beatty for validation against the LiDAR data. A total of 80 points were compared, with average vertical accuracy of 0.029 m RMSE (1 sigma). Minimum and maximum differences were -0.259 and +0.547 m. The minimum and maximum difference points were investigated and no obvious explanations were apparent. The LiDAR ground surface around these points was clear open flat ground (Vekta, 2011).

2.3.3 QSpatial environmental attribute datasets

Digital spatial layers of Fitzroy drainage basin sub-area, watercourses, Queensland Floodplain Assessment Overlay, surface geology, land systems, soil erodibility, woody foliage protective cover, NDRP Storm Tide Hazard Interpolation, highest astronomical tide, and usual high spring tide, covering the area of interest were downloaded from Queensland Government Queensland Spatial Catalogue (QSpatial) (http://qldspatial.information.qld.gov.au/catalogue). All the descriptions of the data layers provided below were sourced from QSpatial metadata.

Fitzroy Drainage Basin Sub-Area was from Drainage basin sub areas – Queensland, published 1/06/2020. The dataset was captured at 1:100 000. The seaward edge of this data aligns with the Coastline and State Border - Queensland dataset. The boundary of the Styx River catchment on this layer differed in detail to that derived by this study using terrain analysis. The difference is explained by the higher resolution elevation data used in this study to delineate the Styx River catchment boundary.

Watercourse data were from ‘Watercourse lines - North East Coast drainage division - central section’ published 5/05/2015, although the streamlines within the area of interest were compiled in 2009. The watercourses are connected and flow directed; a sub-type of connector flows through waterbodies to create a linear network for hydrological modelling. Features are attributed with perenniality, Strahler Stream Order, hierarchy (Major or Minor) and names where available. Features were captured or updated from the best available imagery with an attribute within the data describing the source and reliability. Data sources include Queensland ortho-photography, satellite Imagery (SPOT 5), and Geoscience Australia 1:250,000 scale watercourse lines. Features within this dataset have been progressively updated by drainage basin using imagery to 1:25,000 mapping specifications, but only 1:100,000 mapping specifications have been achieved for the Fitzroy basin. This watercourse layer is similar to digital layer ‘Wetland data - version 4 - wetland lines – Queensland’, which ostensibly maps the same watercourses at 1:100,000 scale. The difference is that the wetland lines depict many of the watercourses as discontinuous, and appear to be sourced directly from the Geoscience Australia 1:250,000 topographic map series. Thus, the process of updating maps to a more detailed scale resulted in fewer drainage lines being depicted as discontinuous. For the purposes of this report, the blue lines on the ‘Watercourse lines - North East Coast drainage division - central section’ were all accepted as valid and included in the investigation. Topographically-derived drainage networks generated automatically by algorithms in Geographic Information System (GIS) suggested the presence of additional or alternative dominant drainage lines in some parts of the area of interest. This was not surprising as it would be expected for water to take paths additional to those indicated on topographic maps. For consistency, only the streams digitally mapped as blue lines at 1:100,000 scale were included for consideration in this report.

The layer ‘Queensland Floodplain Assessment Overlay’ (QFAO) represents a floodplain area within drainage sub-basins developed for use by local governments as a potential flood hazard area. It represents an estimate of areas potentially at threat of inundation by flooding, mapped at 1:100,000 scale. The data were developed through a process of drainage sub-basin analysis utilising data sources including 10 metre contours, historical flood records, vegetation and soils mapping and satellite imagery. Initial inspection of the QFAO layer suggested that in the area of interest the extent of the floodplain overlay far exceeded the modelled 100 year ARI flood extent. Also, the floodplain extent covered wide areas not mapped as alluvial geology, so the QFAO was not used in this report as a representation of the extent of alluvium.

Geology was from ‘Detailed surface geology – Queensland’, a digital representation of the distribution or extent of geological units represented by polygons with a range of attributes including unit name, age, lithological description and an abbreviated symbol for use in labelling the polygons (Table 2). The polygons were extracted from the Rock Units Table held in Department of Natural Resources, Mines and Energy MERLIN Database. The data date from the period 2004 to 2018. The key attribute of interest to this report was age of the lithological unit.

Table 2. Key to the main surface geology lithological units mapped in the CQC Project area on layer ‘Detailed surface geology – Queensland’.

Symbol	Rock Unit Name	Age	Lithological summary
Kx	Styx Coal Measures	Early Cretaceous	Quartzose sandstone, green lithic sandstone, mudstone, conglomerate, carbonaceous shale and coal
Pb	Back Creek Group-Pb	Late Permian	Predominantly massive, cleaved mudstone and siltstone (commonly with concretions), minor lithic sandstone
Pbm	Boomer Formation	Late Permian	Lithic sandstone, siltstone, mudstone, rare conglomerate
Pc/b	Carmilla Beds/b	Earlier Permian	Altered (uralitised and carbonatised) locally amygdaloidal, aphyric basalt
Pc/s	Carmilla Beds/s	Early Permian	Siltstone and mudstone, volcanilithic sandstone and conglomerate; minor altered basalt and local rhyolitic to dacitic volcanic rocks
Qa	Qa-QLD	Quaternary Alluvial	Clay, silt, sand, gravel; flood-plain alluvium
Qf	Qf-QLD	Quaternary Alluvial	Clay, silt, sand and clayey to sandy gravel; alluvial fans, sheetwash and floodout sheets
Qhe/s	Qhe/s-YARROL/SCAG	Holocene	Sand, muddy sand, mud and minor gravel; estuarine channels and intertidal sand banks and flats
Qpa	Qpa-QLD	Pleistocene Alluvial	Clay, silt, sand, gravel; flood-plain alluvium on high terraces
Qr,Qf>Kx	Qr-QLD,Qf-QLD>Styx Coal Measures	Quaternary Colluvial	Clay, silt, sand, gravel and soil: colluvial and residual deposits
TQa	TQa-QLD	Late Tertiary – Quaternary	Locally red-brown mottled, poorly consolidated sand, silt, clay, minor gravel; high-level alluvial deposits, generally dissected, and related to present stream valleys
TQr>Kx	TQr-QLD>Styx Coal Measures	Late Tertiary – Quaternary	Clay, silt, sand, gravel and soil; colluvial and residual deposits (generally on older land surfaces)

Land systems were from ‘Land systems - land systems of the Capricornia coast - CCL3’. The boundaries of the land systems were based on the coincidence of dominant landform, soils and vegetation communities. Polygon boundaries were drawn as probabilistic interpretations of changes in soil or land type. Eleven land systems occurred in the CQC Project area (Table 3). Mapping was based on aerial photography interpretation and field traverses with site descriptions ranging from one observation to an area of 1000 hectares, to one observation to an area of 400 hectares. The area of interest was covered by Map 1 St Lawrence Marlborough Area. The data were published in printed form in 1995 based on data captured in 1992.

Table 3. Key to land systems mapped in the CQC Project area on layer 'Land systems - land systems of the Capricornia coast - CCL3'.

Land System	Agricultural Class meaning	Description
Ar - Artillery	Pasture Land - Native pastures	Bleached sandy and loamy surface, brown and grey, alkaline sodic duplex soils formed on undulating low hills, rises and fans on fine grained sedimentary rocks; Eucalypt woodland.
Bl - Blackwater	Crop Land	Brigalow plains and cracking clay soils on weathered Tertiary clay and older rocks along the central axis of the area.
Hl - Headlow	Pasture Land - Native pastures	Bleached loamy, clay loamy and silty surface, brown and grey, alkaline sodic duplex soils formed on broad, level to gently undulating alluvial plains and fans on silty and fine textured alluvium; Mixed eucalypt woodland.
Kt - Kooltandra	Pasture Land - Native pastures	Bleached clay loamy and silty surface, brown and grey, alkaline sodic duplex soils formed on undulating rises and plains on sedimentary rocks and unconsolidated sediments; Gum-topped box and rosewood woodland.
Pv - Plainview	Pasture Land - Native pastures	Black and grey, strongly sodic cracking clays or bleached loamy and clay loamy surface, brown and grey, alkaline sodic duplex soils formed on gently undulating to level plains on unconsolidated fine and medium textured sediments; Eucalypt woodland.
Rd - Rosewood	Pasture Land - Native pastures	Bleached sandy and loamy surface, brown and grey, alkaline sodic duplex soils formed on rolling low hills and rises on hard sedimentary rocks; Rosewood open forest with emergents.
So - Somerby	Pasture Land - Sown pastures, and native pasture on high fertility soils	Gilgaied plains with brigalow and cracking clay soils on weathered Tertiary clay along the central axis of the area.
Sx - Styx	Crop Land	Brown, massive, fine sandy loams formed on narrow floodplains along the Styx River and Wellington Creek; Eucalypt woodland.
Tb - Tooloomba	Pasture Land - Native pastures	Bleached sandy and loamy surface, brown and grey, alkaline sodic duplex soils formed on gently undulating rises and plains on sedimentary rocks; Eucalypt woodland.
Tl - Torilla	Pasture Land - Native pastures	Red, structured gradational clay loams and uniform clays formed on undulating rises and low hills on deeply weathered sedimentary and metamorphic rocks; Eucalypt woodland.
Ws - Woodstock	Pasture Land - Native pastures	Red, massive, gradational loams and clay loams or red, structured gradational clay loams formed on dissected low plateaus on gently dipping sedimentary rocks; Eucalypt woodland.

Surface soil erodibility data were from 'Fitzroy NRM region surface soil erodibility - Central Queensland', published 24/04/2017. This raster dataset, in this report termed 'Surface soil erodibility', classifies surface soil erodibility on a 90 × 90 m grid at the sub-catchment scale. Soil erodibility is the susceptibility of soils to detachment and transportation by erosive agents. It is a composite expression of those soil properties that affect the behaviour of a soil and is a function of the mechanical, chemical and physical characteristics of the soil (Zund, 2017). Surface soil stability is categorised into 4 categories. The higher the number, the greater the erodibility (Table 4).

Table 4. Key to surface soil stability cell values on layer ‘Fitzroy NRM region surface soil erodibility - Central Queensland’. Descriptions are from Zund (2017).

Code	Category	Description
0	Not assessed	-
1	Moderately stable surface soils	Soils that are unlikely to be dispersive. These are usually well-structured and resilient to degradation
2	Non-cohesive surface soils	Sandy soils that are non-structured or only weakly so and non-cohesive. These soils are easily eroded
3	Dispersive surface soils	Erodible loamy or clayey soils that are sodic, hardsetting and likely to disperse in water
4	Highly erodible surface soils	Highly erodible clay soils that are sodic and dominated by expanding/swelling clays that disperse readily

A secondary soil erodibility dataset is ‘Fitzroy NRM Region soil erodibility - Central Queensland’. This dataset, termed here ‘Overall inherent soil erodibility’, classifies overall inherent soil erodibility on a 90 × 90 m grid. Overall inherent soil erodibility is a combination of the stability of the surface soil and the dispersibility of the subsoil (Zund, 2017). Surface soil stability and subsoil dispersibility were combined to form 17 categories. The higher the number, the greater the vulnerability to erosion (Table 5, Table 6).

Vegetation structure and coverage was from ‘Wooded extent and foliage projective cover - Queensland 2013’ Foliage Projective Cover (FPC) is the percentage of ground area occupied by the vertical projection of foliage. The methodology was described in Armston et al. (2009) and Gill et al. (2017). The FPC mapping is based on an automated decision tree classification technique applied to dry season (May to October) Landsat-5 TM, Landsat-7 ETM+ and Landsat-8 OLI imagery for the period 1988-2013. Pixels were classified as woody or not woody, their foliage projective cover was quantified, and pixels were then classed as forest or other wooded lands based on cover density. Field data from 2002 to 2014 were used to calibrate the remotely sensed data. The wooded extent product has a nominal accuracy of 85%. Image value = FPC + 100 (i.e. FPC of 5% = image value of 105). Range is 100-200 which is equivalent to 0-100% FPC.

Extent of tides for a range of average recurrence intervals (ARI) was from ‘NDRP Storm Tide Hazard Interpolation’. The purpose of the NDRP (National Disaster Resilience Program) Storm Tide Hazard Interpolation study was to map, based on a consistent methodology using data from existing studies, the ARI for a range of ocean water levels for each coastal LGA (Local Government Area). The methodology was described in GHD (2014). The tide extent surfaces were developed via inland extrapolation of coastal levels (the so-called 'bathtub' approach) and thus hydraulic gradients were not been assessed. The flood extents are considered indicative and are subject to the accuracy of the Queensland Government 10 m DEM. The levels modelled corresponded to the 20, 50 ,100, 200, 500, 1,000 and 10,000 year ARI event, plus the estimated Theoretical Maximum Storm Tide (TMST) level.

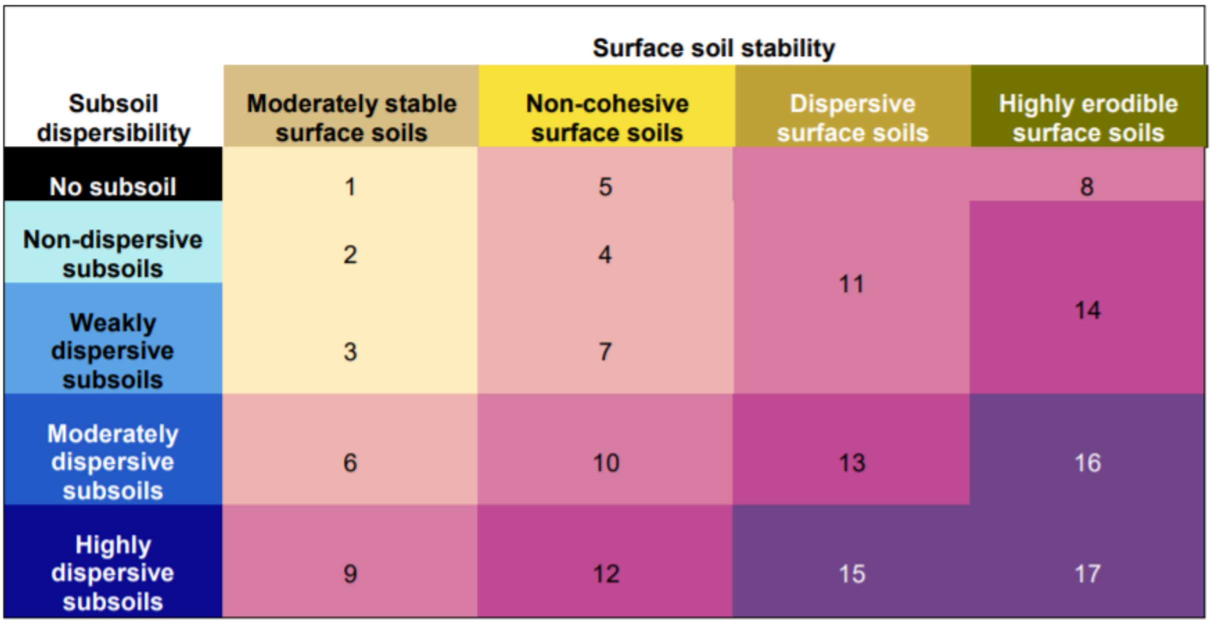
The extent of the highest astronomical tide was from ‘Highest astronomical tide – Queensland’. The highest astronomical tide line represents an approximation of the land-tidal water interface at the highest water level that can be predicted to occur under any combination of astronomical conditions. The data were derived from information obtained from Queensland tide gauges and digital elevation models generated from LiDAR surveys. The data can be considered to date to 2009, which corresponds to the date the LiDAR data were flown.

The point to which the high spring tide ordinarily flows and reflows in the Styx River, whether due to a natural cause or to an artificial barrier was identified by ‘Watercourse identification map - downstream limits – Queensland’. Version 48 was published on 1/05/2020. This point is identified to show the boundary between where water is either managed under the Water Act 2000 or under the Coastal Protection and Management Act 1995. Water services officers from the Departments of Natural Resources, Mines and Energy and the Department of Environment and Science collaboratively agree on the location of the downstream limit of a watercourse using a number of analytical and measuring techniques, including desktop analysis using aerial imagery and other map resources, and optionally a site visit.

Table 5. Key to inherent soil stability cell values on layer 'Fitzroy NRM Region soil erodibility - Central Queensland'. Expected soil characteristics are from Zund (2017).

Code	Category	Expected soil characteristics
Very low erosion vulnerability		
0	Not assessed	
1	Moderately stable surface soils over rock or sediment	Shallow loamy or clayey soils
2	Moderately stable surface soils over nondispersive subsoils	Loamy or clayey soils over non-dispersive subsoils
3	Moderately stable surface soils over weakly dispersive subsoil	Loamy or clayey soils over weakly dispersive subsoils
Low erosion vulnerability		
4	Non-cohesive surface soils over non-dispersive subsoil	Sandy massive surface soils over non-dispersive subsoils
5	Non-cohesive surface soils over rock or sediment	Shallow sandy massive soils
6	Moderately stable surface soils over moderately dispersive subsoils	Loamy or clayey soils over moderately dispersive subsoils
7	Non-cohesive surface soils over weakly dispersive subsoils	Sandy massive surface soils over weakly dispersive subsoils
Moderate erosion vulnerability		
8	Clayey soils that erode and/or slake readily over rock or sediment	Clay soils that are sodic and dominated by expanding/swelling clays that disperse readily
9	Moderately stable surface soils over highly dispersive subsoils	Loamy or clayey soils over highly dispersive clayey subsoils
10	Non-cohesive surface soils over moderately dispersive subsoils	Sandy massive surface soils over moderately dispersive subsoils
11	Weakly dispersive clayey soils	Loamy or clayey soils that are sodic throughout the profile, have hardsetting surfaces and are weakly dispersive
High erosion vulnerability		
12	Non-cohesive surface soils over highly dispersive subsoils	Sandy massive surface soils over highly dispersive subsoils
13	Dispersive clayey soils	Loamy or clayey soils that are sodic throughout the profile, have hardsetting surfaces and are moderately dispersive
14	Clayey surface soils that erode and/or slake over weakly dispersive subsoils	Clay soils that are sodic and dominated by expanding/swelling clays that have weakly dispersive sodic subsoils
Very high erosion vulnerability		
15	Dispersive clayey surface soils over highly dispersive subsoils	Loamy or clayey surface soils that are sodic and hardsetting over highly dispersive clay subsoils
16	Clayey surface soils that erode and/or slake over moderately dispersive subsoils	Clay soils that are sodic and dominated by expanding/swelling clays that have moderately dispersive sodic subsoils
17	Clayey surface soils that erode and/or slake over highly dispersive subsoils	Clay soils that are sodic and dominated by expanding/swelling clays that have highly dispersive sodic subsoils

Table 6. Overall inherent soil erodibility based on surface soil stability and subsoil dispersibility. Source: Zund (2017, Table 2).



Subsoil dispersibility	Surface soil stability: Moderately stable surface soils	Non-cohesive surface soils	Dispersive surface soils	Highly erodible surface soils
No subsoil	1	5	11	8
Non-dispersive subsoils	2	4		14
Weakly dispersive subsoils	3	7		
Moderately dispersive subsoils	6	10	13	16
Highly dispersive subsoils	9	12	15	17

2.3.4 Soil Map Units

HESSE (2020) undertook an agricultural land capability and soil suitability assessment in the CQC Project area. Soil profiles were described initially from reconnaissance survey auger holes to 1.5 m or refusal to develop a soil map key. This was followed by detailed soil descriptions and sampling made from test pits excavated to 2 m at selected sites that were considered central to, and typical of, each map unit. Five soil units were mapped by HESSE: Alluvial soils (gravelly and non-gravelly), Earthy Soils – Kandosols, Sodic texture-contrast duplex soils – Sodosols, and Cracking clay soils – Vertosols (Table 7).

Table 7. Soil units mapped by HESSE (2020).

Soil unit concept	Soil Order	Location and description
Alluvial Soils, Gravelly Shallow Sand, Gravel Loam	Tenosols, Rudosols	Narrow band along active river beds.
Alluvial Soils, Non-gravelly, Sandy Loam to Clay textures	Tenosols, Rudosols, Vertisols	Occurs on river flats and terraces, cleared for pasture, no rocks, no microrelief, imperfectly drained, slope <1%; Alluvial Soils with minimal profile development on Tooloomba and Deep Creek narrow floodplains
Red and Brown Gravelly Earths, Sandy Loam Topsoil over Clay Loam Subsoil	Kandosols	On higher elevation land and slopes.
Vertic Hypernatic Grey and Brown Sodosols, Gravelly Clay-loamy Clayey	Sodosols	Occurs on terraces, cleared for pasture, gravelly, crabhole gilgai microrelief, imperfectly drained, slope <1%;Sodic soils with contrasting topsoil and subsoil texture on terrace plains and undulating rises of Deep Creek
Brown and Grey Sodic Vertosols Non-gravelly Medium Clay over Medium Heavy Clay	Vertosols	Occurs on terraces, cleared for pasture, gravelly, melonhole gilgai microrelief, imperfectly drained, slope <1%; Uniform textured cracking clay soils with shrink-swell properties on terrace plains and alluvial plains of Tooloomba Creek and the Styx River

2.3.5 Aerial imagery

The current landuse and land cover was represented by imagery dated 03/12/2016, sourced online from World Imagery through Global Mapper GIS. Historical aerial imagery was sourced from QImagery (https://qimagery.information.qld.gov.au/) and Google Earth (Table 8). The QImagery data were ostensibly georeferenced, but the stated projection was incorrect. The images were loaded to Global Mapper GIS and rectified against ground control points.

Table 8. Historical aerial imagery sourced for this report.

Image Series	Date of image	Colour	Scale
Styx 1953	01-06-1953	Black and White	1:26,000
Marlborough 1975	27-06-1975	Black and White	1:30,000
Marlborough 1985	23-06-1985	Black and White	1:24,000
Marlborough 2003	8-07-2004	Colour	1:40,000
Google Earth 2018	20-09-2018	Colour	-

2.3.6 Watercourse flood hydraulic characteristics

CDM Smith (2018c) undertook a flood assessment for Tooloombah Creek, Deep Creek and the Styx River. The methodology used XP-RAFTS to model storm event hydrographs for design rainfall data. The catchment has no discharge gauge to provide calibration data but comparison between peak flows modelled by XP-RAFTS and the Regional Flood Frequency Estimation (RFFE) method for peak flows found that the two methods produced comparable results. The developed case model build involved applying the same temporal patterns and design rainfall intensities as the existing case model, but with the area covered by the open cut pit removed as a contributing area, applying a higher impervious area value to the MIA, diverting upstream flow around the pit and Waste Rock Stockpile, and applying a lower impervious value to the waste area. Hydrographs were developed to represent 9.5%AEP, 4.9%AEP, 2%AEP, 1%AEP and 0.1%AEP. Hydraulic modelling of flow in the watercourses was undertaken using MIKE21. The 2011 LiDAR data, resampled to a 10 m grid, were used to represent the topography. The downstream boundary condition did not account for tides.

WRM Water & Environment (2020) developed a 2.5 m grid TUFLOW hydraulic model of the watercourses in the CQC Project area, including Barrack Creek, Deep Creek, Tooloombah Creek and upper Styx River. The model was run for hydrographs representing 10%, 5%, 2%, 1% and 0.1% AEP peak design discharges, as well as the probable maximum flood (PMF) discharge based on design rainfall data (rainfall depths, areal reduction factors and temporal patterns) applied in accordance with ensemble event procedures in Australian Rainfall and Runoff (AR&R). The WRM Water & Environment (2020) model is more recent and higher spatial resolution than the model of CDM Smith (2018c). On this basis, it was preferred for the geomorphic assessment. Modelled hydraulic spatial data from the 10% AEP and 1% AEP events were evaluated in this report. The main variables of interest were velocity and bed shear stress (BSS).

2.4 Geomorphologically-Relevant Variables

Two main groups of variables were of interest to geomorphological characterisation:

- Landscape-scale variables
- Stream reach- and point-scale variables

2.4.1 Landscape-scale variables

Landscape-scale variables provide information to help explain catchment-scale geomorphological processes, and risks associated with mining impacts; they also provide contextual information to help explain local-scale physical processes and forms. Information was compiled at the landscape-scale regarding:

- Topography
- Drainage network
- Geology
- Land systems
- Soils

- Vegetation
- Tidal extent

2.4.2 Stream reach- and point-scale variables

Stream-reach and point-scale variables were used to characterise geomorphological processes and forms for the purpose of baseline classification of stream type, condition and fragility/resilience to disturbance. Variables were selected mainly on the basis of their relevance to stream classification, and potential impacts of open-cut mining on streams.

Fragility is the ease of adjustment of bed material, channel geometry, and channel planform when subjected to degradation or certain threatening activities, and resilience is the property of having low fragility (Cook and Schneider, 2006; Brierley et al., 2011). The determination of stream fragility is based on the adjustment potential of three main characteristics of each geomorphic category. These include the adjustment potential of each category’s channel attributes (geometry, size and connection to floodplain), planform (lateral stability, number of channels and sinuosity) and bed character (bedform and bed materials) (Cook and Schneider, 2006). Different stream types have characteristic levels of fragility. Stream types with “Low fragility” are resilient or “unbreakable”, those with “Medium fragility” have local adjustment potential, and those with “High fragility” have significant adjustment potential (Cook and Schneider, 2006). Following on from this, the conservation and rehabilitation priority of stream reaches can be determined on the basis of geomorphic fragility and condition. Streams reaches with high fragility and poor condition are rated low priority, while reaches with low fragility that are in good geomorphic condition are rated the highest priority for protection.

River Styles® is a system for classifying stream geomorphic type based on valley setting, level of floodplain development, bed materials and reach-scale physical features within the stream (Brierley et al., 2011). The potential for physical recovery after disturbance depends on stream geomorphic condition, whereby streams in good condition (undisturbed and close to natural state) are more likely to be resilient and recover faster than those that are already degraded (Outhet and Cook, 2004; Brierley et al., 2011).

This report classified the streams in the CQC Project area according to river type and geomorphic condition, using an approach that was consistent with River Styles®. This required collection of data concerning valley setting, stream slope, channel dimensions and shape, and bed material type.

Geomorphic condition is strongly linked to the degree of naturalness and extent of cover of riparian vegetation (Outhet and Cook, 2004; Outhet and Young, 2004a). These considerations justify the inclusion, in geomorphologic assessments, of variables that characterise riparian and in-channel vegetation and related large woody debris, both of which contribute to the structural stability of streams (Abernethy and Rutherfurd, 2000; Gippel, 1995; Gippel et al., 1996). The influence of vegetation on stream processes declines rapidly with distance from the channel edge. This report defined the riparian zone as a distance of up to 50 m from the channel edge, which is consistent with that used by Munné et al. (2003) and Raven et al. (1998).

Pools and riffles are the two habitat elements of streams that have received the most attention from a geomorphological and ecological perspective (Frissell et al., 1986; Maddock, 1999). Pools are commonly a focus of habitat assessments because of their ecological importance, especially as a refuge when streams stop flowing (Bond et al, 2008). Riffles act as hydraulic controls on pools in alluvial streams. Comprehensive mapping of pool and riffle morphology would require sampling and survey at a much more detailed spatial scale than that used in this investigation. Water present in the channels at the time of the LiDAR flights prevented mapping pools and riffles from available topographic data.

The frequency, magnitude, type and location of geomorphic change on rivers depends on the distribution of forces that act to mobilise, transport, and deposit sediments, and the distribution of characteristics of the materials that resist erosive forces and favour deposition. The characteristics of the materials that resist erosive forces can be characterised by soil type and vegetative cover, as described above. The forces acting to erode river channels and floodplains can be characterised by velocity and bed shear stress. The methodology is described in the following subsections.

Based on the above considerations, reach- and point-scale variable groups considered relevant to this report were:

- Stream geomorphic type and condition,
- Riparian vegetation,
- Channel slope,
- Channel dimensions,

- Channel bed materials,
- Velocity, and
- Bed shear stress.

2.4.3 Method of maximum permissible velocity

Chow (1981, p. 164) noted that:

> "*The behavior of flow in an erodible channel is influenced by so many physical factors and by field conditions so complex and uncertain that precise design of such channels at the present stage of knowledge is beyond the realm of theory*."

Since that time there have been developments in the level of sophistication of river channel modelling capacity, but there have been no major advancements in relevant theory. The methodology used in this assessment is the traditional one, as described in Chow (1981, pp. 164-191) and other popular channel hydraulics texts. The two methods that have been most commonly applied to this type of problem are the:

- method of permissible velocity, and
- method of bed shear stress (also known as tractive force)

It is important to realize that while these approaches have been applied extensively in the river engineering industry throughout the world for decades, like all empirically based approaches, they remain subject to uncertainty.

The maximum permissible velocity (U_{max}) is the greatest mean channel velocity (U) that will not cause erosion of the channel body. A channel is stable when:

$$U < U_{max} \tag{1}$$

Tables of maximum permissible velocity appear in many channel design, engineering and hydraulics publications (e.g. Chang, 1988), and they are all based on values for canals given by Fortier and Scoby (1926), and from the USSR (Anon, 1936), although some agencies have adjusted these standard values on the basis of local empirical knowledge (e.g. Stallings, 1999) (Table 9).

Table 9. Maximum permissible velocities for channels formed in a range of materials. Assumes a flow depth of 1 metre. Note: no vegetative cover.

Bed material (USDA soil description)	Maximum permissible velocity (m/s)		
	Clear water[3]	Water transporting fine suspended solids[3]	Values used in Virginia (USA)[4]
Ordinary firm loam[1]	0.8	1.1	0.9
Stiff clay, very colloidal[2]	1.1	1.5	1.0
Alluvial silts, colloidal	1.1	1.5	-
Alluvial silts, non-colloidal	0.6	1.1	-
Sandy loam, non-colloidal	0.5	0.8	-
Fine gravel	0.8	1.5	-

1. Plastic clay soil; mixture of clay, sand, and/or gravel, with minimum fines (silt and clay) content of 36% (Stallings, 1999).

2. Moderately to highly plastic clay; mixtures of clay, sand, and/or gravel, with minimum clay content of 36% (Stallings, 1999).

3. Fortier and Scoby (1926) – see Chow (1981, p. 165). The term 'clear water' essentially means water with concentrations of suspended solids <1,000 mg/L (Bos, 1994).

4. Stallings (1999).

Chow (1981) did not define what was meant by "*water transporting fine suspended solids*", but it would appear from Bos (1994, p. 769) that this refers only to very high concentrations of suspended solids, in the order of >20,000 mg/L, while the term 'clear water' essential means water with concentrations of suspended solids <1,000 mg/L. 'Clear water' would apply in nearly all situations in Australia.

The values given in Table 9 assume a bare channel surface (i.e. no grass or other lining or vegetation). Vegetation failure usually occurs at much higher levels of flow intensity than for soil (Fischenich, 2001) (Table 10, Table 11). The values given in Table 10 and Table 11 are average values for channels, and assume a reasonable depth of flow. In shallow flow situations, as would generally occur on floodplains, it is reasonable to assume that surfaces covered with sod forming grass would generally tolerate velocities of up to 2 m/s.

Table 10. Maximum permissible velocities for channels with slopes of 0 – 5% in easily eroded soils lined with grass (assume average, uniform stands of each type of cover). Source: Adapted from Chow (1981, p. 185), using data from the U.S. Soil Conservation Service.

Cover	Maximum permissible velocity (m/s)
Sod forming grass: *Cynodon dactylon* (Bermuda grass)	1.8
Sod forming grass: *Bouteloua dactyloides* (Buffalo grass), *Poa pratensis* (Kentucky bluegrass), *Bromus inermis* (smooth broome), *Bouteloua gracilis* (blue grama)	1.5
Grass mixture	1.2
Bunch grass: *Lespedeza cuneate* (Chinese bushclover or Sericea lespedeza), *Eragrostis curvula* (African, or weeping love grass), *Bothriochloa ischaemum* (yellow bluestem), *Pueraria lobata* (kudzu), *Medicago sativa* (alfalfa or lucerne), Digitaria (crabgrass)	0.8
Annuals	0.8

Table 11. Maximum permissible velocities for channels lined with grass. Source: Fischenich (2001) using data from various sources.

Cover	Maximum permissible velocity (m/s)
Class A turf	1.8 – 2.4
Class B turf	1.2 – 2.1
Class C turf	1.1
Long native grasses (U.S.A.)	1.2 – 1.8
Short native grasses (U.S.A.)	0.9 – 1.2

Flows with long durations often have a more significant effect on erosion than short-lived flows of higher magnitude (Fischenich and Allen, 2000, p. 2-23). Fischenich (2001, p. 6) recommended application of a factor of safety to U_{max} "*when flow duration exceeds a couple of hours*". Graphs are provided in Fischenich (2001) for factoring according to event duration (Figure 3). The duration of flood events naturally varies, although in general the higher the magnitude, the longer is the duration. The relationships imply that the maximum permissible velocity could be very low if the curves asymptote to zero velocity. Of course, the suggestion of a zero maximum permissible velocity is a contradiction in terms, but this raises the idea that there is no such thing as a maximum permissible velocity below which erosion does not occur (Chow, 1981, p. 166).

Anon (1936) gave correction factors for U_{max} for channels greater than 1 m deep (factor >1), and less than 1 m deep (factor <1). A factor of 0.8 would apply to flow 0.25 m deep, 0.9 would apply to flow 0.5 m deep, 1.1 would apply to flow 1.5 m deep, and 1.2 would apply to flow 2.5 m deep. The maximum factor plotted on the graph is 1.3, which would apply to flow 4 m deep. Extrapolation using a power function suggests a correction factor of 1.4 for flow 6 m deep, 1.5 for flow 8.5 m deep, and 1.6 for flow 12 m deep.

Tabulated values of U_{max} are for straight channels, and for sinuous channels U_{max} should be reduced. Lane (1955) recommended reductions in U_{max} of 5% for slightly sinuous channels, 13% for moderately sinuous channels, and 22% for very sinuous channels.

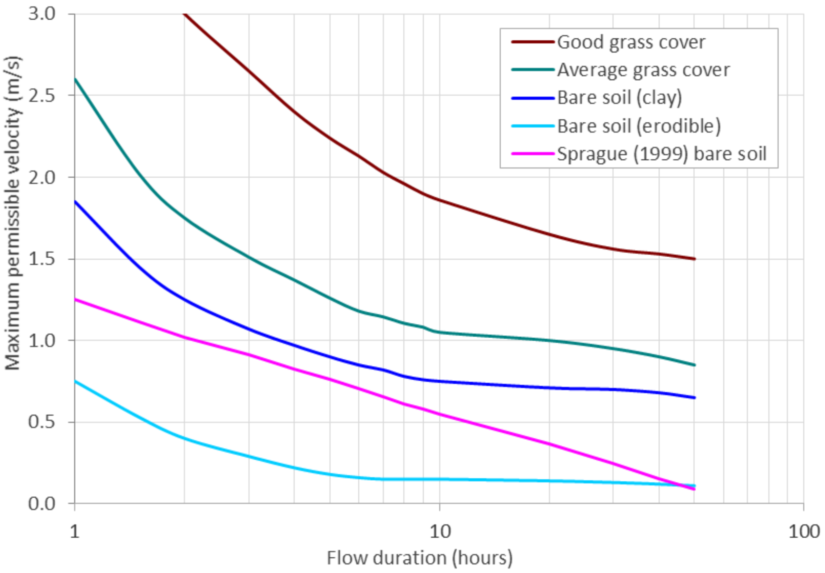


Figure 3. Erosion limits as a function of flow duration. Based on a plots from Fischenich (2001, p. 6) and Sprague (1999).

2.4.4 Method of maximum permissible bed shear stress (BSS)

In one-dimensional (cross-sectional) space, mean bed shear stress (N/m^2) (τ) is conventionally calculated as (Gordon et al., 2004, p. 163):

$$\tau = \rho g R S \qquad (2)$$

where,

R = hydraulic radius of the channel, equal to A/P where A is the cross-sectional area of the flow, and P is the length of the wetted perimeter; in a spatial flood model R of a cell can be represented by water depth at the cell y (m).

S = the energy slope of the water; in a spatial flood model S can be approximated by the water surface slope at the cell (m/m).

ρ = the density of the water (usually assumed to be 1,000 kg/m^3)

g = the acceleration due to gravity (9.8 m/s^2)

In two-dimensional space, in TUFLOW hydraulic model, for each cell, bed shear stress is calculated as:

$$\tau = \frac{\rho g V^2 n^2}{y^{\frac{1}{3}}} \qquad (3)$$

where,

V = velocity of the cell (m/s).

n = Manning's roughness coefficient of the cell

y = water depth of the cell (m)

The formula used in TUFLOW (Equation 3) avoids the use of slope, presumably because the relatively high resolution cells of a 2-D grid can have significant spatial variation in slope, and have negative values (i.e. upstream sloping water surface). The Manning equation predicts velocity from roughness, hydraulic radius and slope. Equation 3 is derived by rearranging the terms of the Manning equation to predict slope from roughness, hydraulic radius and velocity. This expression is then substituted for slope in Equation 2. Assuming depth is equivalent to hydraulic radius then gives Equation 3.

Maximum permissible shear stress (τ_{max}) is the maximum unit shear stress (τ) that will not cause serious erosion of the channel.

A channel is stable when:

$$\tau < \tau_{max} \tag{4}$$

Tables of maximum permissible shear stress appear in many channel design, engineering and hydraulics publications (e.g. Chow, 1981; Chang, 1988), and they are all based on values given by the U.S. Bureau of Reclamation (Lane, 1952; Carter, 1953) (Table 12).

When soil is covered by vegetation its resistance to scour is considerably enhanced (Table 13 and Table 14). A critical shear stress in the range 100 – 200 N/m^2 is a reasonable guide to the shear stress required to remove typical native or pasture grass cover found on floodplains and hence initiate stripping of the floodplain surface.

Table 12. Maximum permissible bed shear stress (BSS) for channels formed in fine-grained material. Note: no vegetative cover.

Bed material (USDA soil description)	Maximum permissible shear stress (N/m^2)	
	Clear water[3]	Water transporting fine suspended solids[3]
Ordinary firm loam[1]	3.6	7.2
Stiff clay, very colloidal[2]	12.5	22.0
Alluvial silts, colloidal	12.5	22.0
Alluvial silts, non-colloidal	2.3	7.2
Sandy loam, non-colloidal	1.8	3.6
Fine gravel	3.6	15.3

1. Plastic clay soil; mixture of clay, sand, and/or gravel, with minimum fines (silt and clay) content of 36% (Stallings, 1999).

2. Moderately to highly plastic clay; mixtures of clay, sand, and/or gravel, with minimum clay content of 36% (Stallings, 1999).

3. Chow (1981, p. 165). The term ‘clear water’ essentially means water with concentrations of suspended solids <1,000 mg/L (Bos, 1994).

Table 13. Maximum permissible bed shear stress (BSS) for channels lined with grass. Source: Fischenich (2001) using data from various sources.

Cover	Maximum permissible shear stress (N/m^2)
Class A turf	177
Class B turf	101
Class C turf	48
Long native grasses (U.S.A.)	57 – 81
Short native grasses (U.S.A.)	34 – 45

Table 14. Summary table of threshold bed shear stress (BSS) for erosion of vegetated surfaces from various studies. Source: modified from Blackham (2006).

Vegetation type	Erosion threshold (N/m^2)
Aquatic (swampy) vegetation (Prosser and Slade, 1994)	105
Tussock and sedge (Prosser and Slade, 1994)	240
Disturbed tussock and sedge (Prosser and Slade, 1994)	180
Bunch grass† 20 - 25 cm high (Prosser et al., 1995)	184
Bunch grass† 2 - 4 cm high (Prosser et al., 1995)	104
Bunch grass† (Hudson, 1971)	80 – 170*
Bunch grass† [Ree, 1949 in (Reid, 1989)]	80 – 90*
Cynodon dactylon (Bermuda grass) (Hudson, 1971)	110 – 200*
Cynodon dactylon (Bermuda grass) [Ree, 1949 in (Reid, 1989)]	120 – 180*
Bouteloua dactyloides (Buffalo grass)*, Poa pratensis* (Kentucky bluegrass) (Hudson, 1971)	110 – 200*
Bouteloua dactyloides (Buffalo grass [Ree, 1949 in (Reid, 1989)]	110 – 180*

† Any of various grasses of many genera that grow in tufts or clumps rather than forming a sod or mat.

* These ranges summarise data for a variety of soil types/hillslopes. See Reid (1989) and Hudson (1971) for more details.

Tabulated values of maximum permissible shear stress are for straight channels, and for sinuous channels the maximum permissible shear stress should be reduced. Lane (1955) recommended reductions of 10% for slightly sinuous channels, 25% for moderately sinuous channels, and 40% for very sinuous channels.

It should be noted that unit bed shear stress is not uniformly distributed along the wetted perimeter. Computed values of shear stress based on average cross-section conditions may be adjusted to account for local variability and instantaneous values higher than mean (Fischenich, 2001). A number of procedures exist for this purpose. Most commonly applied are empirical methods based upon channel form and irregularity. According to Chow (1981, p. 170), for trapezoidal channels, the maximum shear stress on the sides of a channel is close to $0.76\,\tau$. Fischenich (2001) recommended that for straight channels, the local maximum shear stress can be assumed to be $1.5\,\tau$.

Temporal variations in bed shear stress occur in turbulent flows, and these can be 10 – 20% higher than the mean value. Fischenich (2001) suggested that computed bed shear stress values be adjusted by factor of 1.15.

Bed shear stress is higher in sinuous reaches than in straight reaches. Simple 1-D hydraulic modeling such as HEC-RAS does not usually account for this, so Fischenich (2001) suggested an adjustment be made to the computed bed shear stress values, to calculate the maximum shear stress on the bend (τ_{bend}) as a function of the planform characteristics:

$$\tau_{bend} = 2.65\tau(R_c/W)^{-0.5} \qquad (5)$$

where R_c is the radius of curvature and W is the top width of the channel. When assessing channel stability, the computed shear stress values do not need to be adjusted for sinuosity in this way if a sinuosity correction factor is applied to the maximum permissible shear stress value, as described previously (i.e. either approach can be applied to a case, but not both).

2.4.5 Australian Coal Association Research Program (ACARP) design criteria for stream diversion design in the Bowen Basin

ACARP guidelines for diversion design were based on the findings of a series of research projects conducted between 1999 and 2002 on performance of existing diversions (White et al., 2014). One of the elements of the

ACARP guidelines often used for diversion design is a table of hydraulic criteria. The criteria form part of the Department of Natural Resources and Mines (2014) guidelines for diversions.

The table of hydraulic design criteria in DNRM (2014, p. 33) is reproduced here (Table 15). The reference cited for the critical hydraulic values provided by DNRM (2014) was Hardie and Lucas (2002).

A similar table of criteria was provided in SKM (2009). Parsons Brinkerhoff (2010) and Kellogg Brown & Root (2013) (Table 16), quoting the source as Hardie and Lucas (2002) [also referred to as ACARP (2002)] and/or Vernon (2008) [also referred to as DERM (2008) and a later version as DERM (2011)]. The table differs from that provided by DNRM (2014) (Table 15) in values for stream power and bed shear stress for the 50 year ARI flood. Stream power (W/m^2) is the product of shear stress and velocity.

A third table of criteria was provided by White et al. (2014), also citing Hardie and Lucas (2002) as the source. This table was referred to by White et al. (2014) as "*(…ACARP design criteria)…adopted by Queensland regulators in 2002*". In this case, differing sets of criteria were provided for the three different stream types incised, limited capacity and partly bedrock controlled (Table 17). While 'incised' and 'partially bedrock controlled' have conventional meanings with respect to geomorphic stream type, White et al. (2014) did not define the meaning of 'limited capacity'. 'Capacity' could refer to sediment transport or discharge, or both, and the term 'limited' is relative. The criteria values suggest 'limited capacity' refers to channels on the lower end of the energy spectrum and relatively small in size relative to their flood discharge magnitudes, but they could also be of an expected size with high roughness.

Table 15. Guideline values for average stream powers, velocity and bed shear stresses (BSS) for streams within the Bowen Basin. Source: DNRM (2014, p. 33).

Flood scenario	Stream power (W/m^2)	Velocity (m/s)	Bed shear stress (N/m^2)
2 year ARI (no vegetation)	<35	<1.0	<40
2 year ARI (vegetated)	<60	<1.5	<40
50 year ARI	<150	<2.5	<50

Table 16. Guideline values for average stream powers, velocity and bed shear stresses (BSS) for streams within the Bowen Basin. Source: Vernon (2008).

Flood scenario	Stream power (W/m^2)	Velocity (m/s)	Bed shear stress (N/m^2)
2 year ARI (no vegetation)	<35	<1.0	<40
2 year ARI (vegetated)	<60	<1.5	<40
50 year ARI	<220	<2.5	<80

Table 17. Typical values for dependent variables identified for sample stream reaches; ACARP design criteria adopted by Queensland Government in 2002. Source: White et al. (2014).

Stream type/ Flood scenario	Stream power (W/m^2)	Velocity (m/s)	Bed shear stress (N/m^2)
Incised			
2 year ARI	20 - 60	1.0 – 1.5	<40
50 year ARI	50 - 150	1.5 – 2.5	<100
Limited capacity			
2 year ARI	<60	0.5 – 1.1	<40
50 year ARI	<100	0.9 – 1.5	<50
Bedrock controlled			
2 year ARI	50 - 100	1.3 – 1.8	<55
50 year ARI	100 - 350	2.0 – 3.0	<120

The ACARP guidelines are similar to the criteria recommended by the maximum permissible velocity method. The maximum permissible velocity for a stable unvegetated channel ranges from 0.5 – 1.1 m/s depending on soil type, and 0.8 – 2.4 m/s for vegetated surfaces, although lower values would be appropriate for long duration floods. ACARP guidelines recommended maximum velocities for the 2 year ARI event of 1.0 m/s for unvegetated channels and 1.5 m/s for vegetated surfaces. ACARP recommended a higher tolerable velocity of 2.5 m/s for the 50 year ARI event, whether vegetated or not. Allowing a higher limit of velocity for the larger 50 year ARI flood, even though its longer duration would present a higher risk of channel erosion, was presumably related to the infrequent occurrence of such events. Either the impacts of these large events were not observed in the investigations used to formulate the criteria, or a risk approach was taken, whereby the higher consequence of a 50 year ARI flood was traded for its lower likelihood.

The maximum permissible bed shear stress for a stable unvegetated channel ranges from 2 – 13 N/m^2 depending on soil type, and 30 – 240 N/m^2 for vegetated surfaces, although lower values would be appropriate for long duration floods. ACARP guidelines recommended maximum bed shear stress of 40 N/m^2 for the 2 year ARI event and 50 or 80 N/m^2 for the 50 year ARI event, and these limits apply to both vegetated and unvegetated channels. It seems inconsistent to specify the same thresholds for bed shear stress for vegetated and unvegetated channels when it is well established in the literature that vegetation cover markedly increases resistance to scour and sediment transport.

2.4.6 Erosion risk criteria for bed shear stress and velocity for the main watercourses in the CQC Project area

The main watercourses included in the TUFLOW hydraulic model were Tooloombah Creek, Deep Creek and Barrack Creek. The alluvial floodplain soils within which these watercourses flow were described by HESSE (2020) as Alluvial Soils, Gravelly, Shallow (Tenosols, Rudosols), Sand, Gravel, Loam. On Lower Tooloombah Creek, Styx River and an area of Deep Creek, the floodplain soils were described by HESSE (2020) as Alluvial Soils, Non-gravelly (Tenosols, Rudosols, Vertisols), Sandy Loam, to Clay textures. HESSE (2020) mapped the alluvium as a narrow band that included the channels and inset benches. The high banks of the watercourses would be formed in soils of spatially variable clay, silt and sand content. Most of Deep Creek and Barrack Creek alluvium was situated within soil HESSE (2020) described as Vertic, Hypernatic, Grey and Brown Sodosols, Gravelly, Clay-loamy, Clayey texture. Lower Deep Creek, Tooloombah Creek adjacent to the CQC Project area, and Styx River alluvium was situated within soil HESSE (2020) described as Brown and Grey Sodic Vertosols, Non-gravelly, Medium Clay over Medium Heavy Clay texture. The soil types likely to be found on the floodplains, and thus the bank faces, had clay texture. For the purpose of setting velocity and shear stress thresholds it was assumed that the soils had thresholds equivalent to those of ‘Alluvial silts, colloidal’ in Table 9 and Table 12.

Unvegetated ‘Alluvial silts, colloidal’ has maximum permissible velocity of 1.1 m/s (Table 9). Correction for slight sinuosity using the method of Lane (1955) requires reduction by 5%, to give a maximum permissible velocity of 1.05 m/s. This threshold would fall to around 0.7 m/s for flood durations of 5 hours. Well-vegetated floodplain surfaces should be expected to tolerate velocities of at least 2 m/s without initiation of scour. This would apply for flood durations of 2 – 7 hours.

Unvegetated ‘Alluvial silts, colloidal’ has maximum permissible shear stress of 12.5 N/m^2 (Table 12). Correction for slight sinuosity using the method of Lane (1955) requires reduction by 10%, to give a maximum permissible shear stress of 11.3 N/m^2. Well-vegetated floodplain surfaces should be expected to tolerate shear stresses of 100 N/m^2 to 200 N/m^2 without initiation of scour.

Based on information from the literature and local soil type, values of maximum permissible velocity and bed shear stress were assigned to risk categories for initiation of fluvial scour of floodplain soils in the CQC Project area (Table 18). The maximum permissible velocity and bed shear stress methods, like the ACARP guidelines, specify thresholds of hydraulic criteria that should be interpreted as mean velocities within a defined cross-sectional area, either on a floodplain or within a channel. Higher values would be tolerable for brief periods, or in parts of the cross-section. These thresholds should not be interpreted to mean that there is a single value of velocity or bed shear stress below which a channel is morphologically absolutely stable. These thresholds implicitly integrate what would conventionally be considered categories of risk of scour over management time scales.

Table 18. Risk categories of maximum permissible velocity and bed shear stress (BSS) for initiation of fluvial scour of river bank and floodplain soils of the main watercourses in the CQC Project area. These hydraulic criteria are mean cross-sectional values.

Risk of initiation of scour	Bank and floodplain (well-vegetated)		Bank and floodplain (exposed soil)	
	Shear stress (N/m^2)	Velocity (m/s)	Shear stress (N/m^2)	Velocity (m/s)
Low	< 100[1]	< 2.0[2]	< 11.3[4]	< 1.05[6]
Moderate	100 – 200[1]	2.0 – 3.0[3]	11.3 – 80[5]	1.05 – 1.25[7]
High	> 200[1]	> 3.0[3]	> 80[5]	> 1.25[7]

1. See Table 14
2. See Table 10 and Table 11
3. Assumes good grass cover and flow duration < 2 hours, see Figure 3
4. Assumes 'Alluvial silts, colloidal' and slight sinuosity, see Table 12
5. Assumes 50 year ARI, see Table 16
6. Assumes 'Alluvial silts, colloidal' and slight sinuosity, see Table 9
7. Assumes bare soil, (clay) and flow duration < 2 hours, see Figure 3

2.4.7 Geomorphic effectiveness of trees versus grass cover on river banks

When soil is covered by vegetation its resistance to scour is considerably increased, depending on the vegetation type. Most tables of maximum permissible bed shear stress or velocity for vegetated channels consider only grass, not shrubs or trees. This is because the primary use of the tables is to guide design of drainage channels, which are built to transfer water as efficiently as possible. Trees are not established on drainage channels because of their high resistance to flow. The merits of ground cover, shrubs and trees in protecting banks from erosion has been debated in the literature. It is not universally accepted that trees, as opposed to shrubs or grass, have clear superiority in imparting erosion resistance to river banks. There are published papers that demonstrate superiority of grass over trees in this regard. Also, it is not established in the literature that the level of erosion protection is directly related to the age of trees.

A study of sand-bed channels in NSW by Huang and Nanson (1997) found that streams with trees and shrubs growing on the banks, but also in the bed, were 2.2 times wider than streams with trees on the banks only, implying greater bank instability. Trimble (1997), in a study in Wisconsin, found that streams running through forest were significantly wider than those in pasture. This was confirmed by a New Zealand study by Davies-Colley (1997). However, this latter study found that width was independent of vegetation cover for catchments >3 km^2. It was postulated that as stream power increased with basin area, the protective influence of grassy vegetation became less important.

The studies that have found channels to be narrow under pasture have warned that rehabilitation of channels by re-establishment of forests on riparian zones could lead to channel instability, release of sediment stored in channel banks, and consequent deterioration in water quality. Riparian trees can shade banks, eliminating grass cover, and exposing bank surfaces to erosion. Trimble (1997) warned that restoration of forests in riparian zones may not be good public policy. This suggestion runs counter to the general recommendation of ecologists that riparian forests are preferable to grassed banks (Montgomery, 1997). The widespread narrowing of channels by conversion from forest to pasture has significantly reduced the area of habitat available in channels (Sweeney, 1993; Davies-Colley, 1997).

The process that explains channels being wider under forest is woody debris and in-channel trees deflecting flow onto the banks, which erodes them. This effect is reflected in the high roughness coefficients of channels with woody debris or in-stream growth. It is clear that in certain circumstances, the influence of in-stream and riparian trees deflecting flows and causing widening of a channel can be overridden when vegetation increases channel roughness to the extent that it reduces mean flow velocities (Huang and Nanson, 1997).

Montgomery (1997) pointed out that the contradictory findings on the topic of riparian vegetation and channel stability are due to the highly complex nature of the interaction of stream variables. He stated "This smorgasbord of influences means that simple guidelines and blanket generalizations rarely provide a sound basis for the management of rivers and streams" (p. 328). Similarly, Hession et al. (2008) reviewed the literature on riparian vegetation and channel stability, concluding that there is a high level of uncertainty surrounding the topic. It appears likely that grass cover provides good resistance to erosion in small channels but forest cover would be superior in rivers with high banks where the root systems of trees would play a role in bank stabilisation. Significant stability is also imparted to river bed material by large wood sourced from riparian forests (Gippel, 1995). These geomorphic benefits are additional to the ecological benefits provided by riparian forests relative to the limited habitat variability and ecological diversity typically associated with grass.

In a situation where riparian vegetation is being restored, the maximum permissible shear stress values recommended for grassed surfaces are appropriate over the short-term following establishment of grass cover, and the maximum permissible shear stress range for hardwood tree plantings in Fischenich (2001, their Table 2) (i.e. 20 – 120 N/m^2) is appropriate for a rehabilitated forested surface in the long-term.

2.4.8 Sites of geomorphological significance

Geomorphological character is, for the most part, value-free, in that a stream cannot be ranked in terms of importance based on their geomorphologic character alone. The main relevance of geomorphological character is the implications it has for the ecological character. The exception is geomorphological sites that either represent a specific characteristic of a region, or include an outstanding, rare, or possibly unique geomorphological feature. There is no standard method for classification, or a compiled list, of geomorphologically significant sites in Queensland. No published or anecdotal evidence was found indicating the existence of sites of geomorphological significance within the CQC Project area.

2.5 Terrain Analysis

Geomorphology is concerned with both physical form and physical process. Process involves the dimension of time, so tends to be more difficult to measure and model than form. For this reason, geomorphologic assessments often interpret process on the basis of an analysis of physical form. Terrain analysis is concerned with the automated analysis of landforms using digital elevation data sets. The analysis involves application of algorithms within a GIS (Geographic Information System) at detailed scales over wide areas to map characteristics of interest. Terrain analysis was undertaken using the GIS applications Global Mapper™ V15.2.5 25 June 2014 Build (Blue Marble Geographics).

2.5.1 Topography (digital elevation) definition

The topography of the CQC Project area was defined by a 1 × 1 m DEM derived from the supplied 2011 LiDAR point cloud data and a 1 × 1 m DEM derived from the 2009 Tropical Coasts LiDAR point cloud data. For areas beyond the bounds of the LiDAR coverage, the DEM was extended using 5 m and 25 m DEMs. While major bridges over watercourses had been removed from the LiDAR data, culverts under roads required manual editing to maintain correct drainage pathways. The process was to identify areas requiring editing by examination of aerial photography and LiDAR data, seeking physical evidence of culverts and observing where automatically generated drainage lines were hydrologically incorrect due to blockage by road embankments. A small plane at the elevation of the local drainage path was inserted into the DEM over the obstruction to simulate drainage through the culvert. A total of 46 culverts were inserted into the DEM across the Styx River catchment.

2.5.2 Strahler Stream Order

Stream order was assigned according to the Strahler system, whereby a headwater stream is Order 1, and the order increases by 1 when a stream of a given order meets one of the same order. Stream order was an attribute provided for all stream links in the 1:100,000 digital watercourse dataset. While this dataset contains errors, they mainly affect Order 1 and Order 2 stream links, a large number of which were not assigned an Order. These errors did not affect the higher Order streams that flowed through the CQC Project area.

2.5.3 Sub-catchment areas

The Styx River catchment was defined from a point in the upper-estuary (Figure 2), which excluded small streams flowing directly to coastal areas. Sub-catchments and stream lines were defined using the ‘Generate Watershed’ function of Global Mapper™. This function uses the standard 8-direction pour point algorithm (D-8) (Jenson and Domingue, 1988) to generate a drainage network from the DEM. Depressions in the DEM were first filled, then drainage was generated using parameter settings of minimum stream length 50 m and minimum sub-catchment area 10 ha. This drainage network was intended to emulate that of the 1:100,000 blue line network, but differed in some areas with respect to stream length and position. In areas of the Styx River catchment not within the CQC Project area, the sub-catchments draining to the main tributaries entering the river were merged to form entire catchments.

2.5.4 Stream slope

Slope was evaluated for the main watercourses in the vicinity of the CQC Project area. Long profiles were constructed by sampling the DEM along the automatically defined channel thalwegs at a 5 m spacing. Most of these main watercourses were represented by the 1 m DEM, but parts of some of them were represented by 5 m and 25 m DEMs.

2.5.5 River bank and gully erosion rates

Erosion of the subsoil is thought to be responsible for 90% of the fine sediment load delivered to the Great Barrier Reef (Wilkinson et al., 2016). The majority of this sediment is derived from erosion along gully and stream channels. Gully erosion contributes at least 40%, stream erosion approximately 30%, and some subsoil is eroded from rilling on hillslopes (Wilkinson et al., 2016). To establish a baseline, an assessment was made of the types and rates of gully and river bank erosion occurring over the CQC Project site.

Alluvial gully erosion is likely to be a major sediment source in many large tropical rivers in northern and north eastern Australia, including the Fitzroy (Brooks et al., 2007). In the Gulf region, specific annual sediment yields up to 1,250 t/ha have been estimated for individual gullies (Brooks et al., 2007). Alluvial gully erosion is distinct from incisional features in erodible hillslope colluvium that are explained by exceedance of the critical shear stress of the soil surface. Rather, alluvial gullies are found exclusively within alluvium and can propagate entirely as a result of basal sapping (i.e. the preferential erosion of the sub-soil by dissolution weathering and positive pore pressures). Brooks et al. (2007) and Shellberg (2011) presented a typology of alluvial gully erosion in northern Australia, and developed a conceptual model of their formation and progression. The four types were Linear, Dendritic, Amphitheatre and Continuous Scarp Front (Table 19).

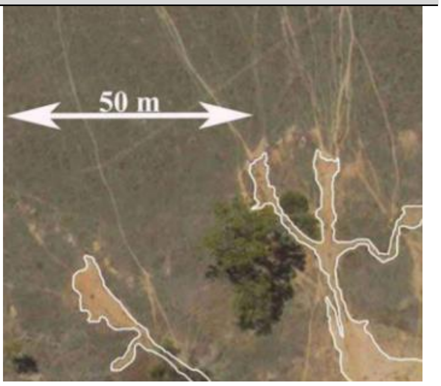
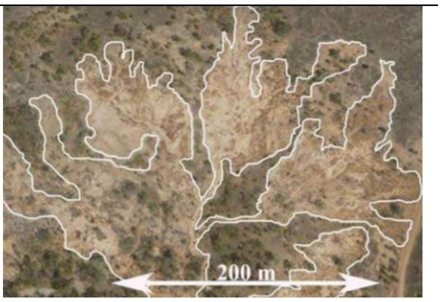
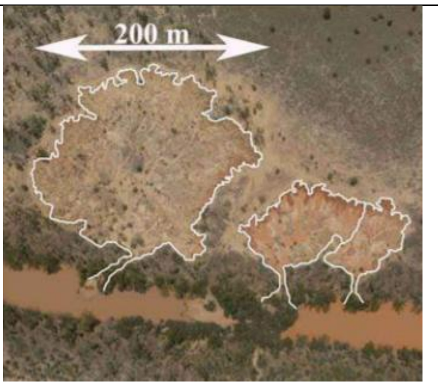
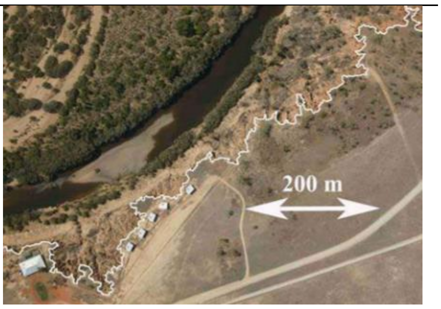
While expansion of alluvial gullies could be related to introduction of roads, it appears that alluvial gullying is an inherent feature of the landscapes where it has been observed (Brooks et al., 2007; Brooks et al., 2009). The Mitchell fluvial megafan, which drains to the Gulf of Carpentaria, is the product of at least five cycles of fan building over the Pleistocene and Holocene (Shellberg, 211). Whilst river incision into the megafan since its formation developed the relief potential for gullying, Brooks et al. (2009) found that other factors such as floodplain hydrology, soil dispersibility, and vegetation cover also influenced the distribution of gullies. Brooks et al. (2009) proposed that the mechanism of initiation of alluvial gullies was concentrated overland flow following rainfall or flooding over steep banks, but whether a gully develops or not depends on surface soil properties and vegetative cover. In the Mitchell River catchment, north east Queensland, the onset of significant gully erosion was coincident with the arrival of cattle (Shellberg et al., 2010; Shellberg et al., 2013). Evidence provided by Brooks et al. (2013) indicated that a similar increase in erosion rate accompanied settlement in the adjoining Normanby River catchment.

Trevithick et al. (2010) mapped gully density on the Fitzroy Basin (not including the Styx River catchment) on the basis of sampling 0.6 m resolution Quickbird satellite imagery. Comparison of mapping of gullies from high resolution imagery with field mapping and mapping from LiDAR-derived DEMs (Prosser, 2018) suggested that relying on imagery can lead to underestimation of gully extent due to obscuration by tree cover (Brooks et al. 2013; Tindall et al. 2014). LiDAR has been applied to gully mapping only in small proportions of regional catchments (Prosser, 2018). One example of application of LiDAR is a study by Benn (2015) of linear gullies on duplex soils at two sites within the Southern Tablelands, NSW. Benn (2015) used high resolution repeat LiDAR surveys to determine the response of the gullies to a 10 – 20 year ARI rainfall event in February-March 2012. LiDAR was captured on 1/08/2011 and 20/06/2012. LiDAR point density was close to 1 point per square metre, and vertical accuracy was 0.1 m at 67% CI. The point cloud data were converted to 1 m DEMs. Benn (2015) found that compared to historical rates of erosion, the 2011 storm event caused little morphological change, with no extension of gully headcuts at either site. The annualised rates of sediment yield from the two sites over the study period were 13.2 – 30.1 and 0.41 – 0.87 t/ha/yr (the range allowed for error). These rates of soil loss are not exceptional, and probably reflect stabilisation of the gullies since 2008 (Benn, 2015).

The availability of LiDAR over the CQC Project area from two dates, Sep-Oct 2009 and 17 June 2011, allowed an analysis of landform change associated with river bank migration and gully erosion over a relatively short period of time. A significant storm event occurred in the Fitzroy River catchment during that period of time. A flood peak of 1,209,975 ML/d was recorded on 1 January 2011 at the gauge Fitzroy River at Riverslea (130003). The flood frequency relationship for this gauge provided by SunWater (2015, p. 3-13) suggests that the December 2010 - January 2011 flood was a 37 year ARI event. A synthetic daily time series of mean discharge in the Styx River provided by WRM Water & Environment suggested that this event peaked on 27 December 2010. Flood frequency analysis suggested this was a 5 to 7 year ARI event in the Styx River.

River bank erosion rate was assessed at a site on the Styx River, just downstream of Ogmore Road bridge. Comparison of the 2009 and 2011 LiDAR data indicated that this was the only site of notable river bank migration in the vicinity of the CQC Project area. Six gully sites in the vicinity of the CQC Project area were selected for assessment of erosion rate between 2009 and 2011 LiDAR surveys. These sites were chosen to be representative of different gully types.

Table 19. Typology of alluvial gully erosion in northern Australia. Source: Shellberg (2011).

Type	Description	Example
Linear	Elongate planform morphologies without well developed secondary drainage networks. They are likely to be an incipient phase of other gully forms, which are usually preceded by rilling. They are also commonly associated with anthropogenic disturbances such as roads, stock tracks, or other linear disturbances that tend to concentrate overland flow	
Dendritic	Associated with well defined drainage networks, separated by distinct interfluves. The gully head is often indistinct, grading relatively gradually into the adjacent floodplain	
Amphitheatre	Often as wide as or wider than they are long, due to the lack of structural control on their lateral expansion. They have well developed head scarps around three-quarters of the gully perimeter, and drain into relatively narrow outlet channels on the proximal or distal sides of alluvial ridges	
Continuous scarp front	Located parallel with the main stem channel of major rivers. They develop from the coalescence of numerous amphitheatre gullies and/or from river bank erosion on meander bends. Thus they are either more mature than other forms	

Two approaches were used to assess geomorphic change at the river bank site. First, the previous positions of the bank edge were determined from interpretation of historical aerial photographs. Second, profile curvature, calculated in GIS from the 2009 and 2011 LiDAR-derived 1 m DEMs, was used to define the edge of the top of bank. Profile curvature greater than 0.1 was used to delineate the strong convex edge of the bank top. The volume of eroded bank material was calculated by subtracting 2009 elevations from 2011 elevations. This was converted to mass by multiplying by a specific gravity of 2.65. A correction was made to adjust for background difference between the 2009 and 2011 LiDAR elevations. This was done by measuring the average difference in elevation of the two LiDAR data sets over a 20 m wide strip of land unimpacted by erosion or deposition that extended around the bank erosion site. A similar procedure was applied to the gully sites to determine the change in soil mass within the defined perimeter of each gully between the dates when the 2009 and 2011 LDAR were flown. The erosion rate was annualised, assuming a period of 631 days between the surveys.

2.6 Stream Geomorphic Type and Condition

2.6.1 Stream geomorphic type classification

The geomorphic stream type classification used here borrowed from, and is consistent with, the River Styles® framework (Brierley and Fryirs, 2000; Brierley and Fryirs, 2005; Brierley and Fryirs, 2006; Fryirs and Brierley, 2006). The River Styles® classification is based on valley setting (whether confined partly-confined or unconfined), level of floodplain development, bed materials and reach-scale physical features within the stream. The classification is largely subjective, based on a mix of topographic map and aerial photograph interpretation, supported by limited field inspection. Some quasi-objective criterion are used. One example is the separation of rivers into low sinuosity and meandering by the threshold of 1.3 for stream length divided by valley length.

The River Styles® framework was designed to cover all Australian stream types, and it is normally applied over the basin or regional scale, with most mapped streams being Order 3 or higher. Across regions or basins a range of different styles would be expected. Most of the styles apply to partly confined and unconfined (i.e. alluvial/lowland) valley settings where streams are relatively large and feature many distinctive units such as levees, pools and riffles, bars, islands, benches, cutoff channels, backswamps, wetlands and floodplains. The streams classed Major in the 1:100,000 Watercourse layer suit this classification system but small-scale Minor streams can be difficult to categorise using this system.

Stream type classification in the CQC Project area was done on the basis of spatial data layers, aerial imagery and ground photography. The subjective nature of classifying stream reaches into geomorphic types (or River Styles®) means that the procedure is uncertain.

2.6.2 Stream geomorphic condition classification

Outhet and Cook (2004) defined geomorphic condition of a reach as:

> "*the capacity of a river to perform the biophysical functions that are expected for that river type within the valley setting that it occupies*"

Geomorphic condition relates primarily to the connections and linkages with the floodplain, reaches up and downstream and more importantly, assesses the effect of human disturbance on the current evolutionary stage (Cook and Schneider, 2006). For use in River Styles® assessments, Outhet and Cook (2004) classified geomorphic condition in according to three categories, with each having a number of identifying characteristics (Table 20).

2.7 Impact Assessment

2.7.1 Types of geomorphic response (event type) to mining related changes

There are four main mining-related agents of change with potential to cause an impact on geomorphological processes and forms in the CQC Project area:

- Removal of a stream channel and its catchment
- Removal of part of a stream, requiring diversion of the stream around the pit
- Hydrological change in the distribution of stream flows
- Hydraulic change, whereby alteration of the channel or floodplain morphology causes a change in bed shear stress, velocity and water depth, which in turn could alter sediment transport, and bed and bank erosion processes.

These potential agents of change could bring about a number of generic geomorphic responses (Table 21) that would constitute an environmental impact with possible implications for environmental values. Some of these risks were assessed directly or indirectly for the EIS by other technical specialists.

Table 20 Categories of stream geomorphic condition defined by Outhet and Cook (2004). The term "Style" is equivalent to the term "stream type" used in this report.

Geomorphic condition	Description
Good condition Stream exhibits all of these characteristics	• River character and behaviour fits the natural setting, presenting a high potential for ecological diversity, similar to the pre-development intact state. • There is no general bed incision or aggradation. The reach has already recovered from major natural and human disturbances and has adjusted to the present flow regime. It has stopped evolving and has adjusted to prevailing catchment boundary conditions. • The patterns and forms of the geomorphic units are typical for the Style. • The Style is consistent with the natural setting and controls. • The reach has self-adjusting river forms and processes, allowing fast recovery from natural and human disturbance. • There is intact and effective vegetation coverage relative to the reference reaches, giving resistance to natural disturbance and accelerated erosion. • The reach has all good condition attributes without artificial controls.
Moderate condition Stream exhibits one or more of these characteristics	• Localised degradation of river character and behaviour, typically marked by modified patterns of geomorphic units. • Degraded forms of geomorphic units, as marked by, for example, inappropriate grain size distribution. • Patchy effective vegetation coverage relative to the reference reaches (allowing some localised accelerated erosion).
Poor condition Stream exhibits one or more of these characteristics	• Abnormal or accelerated geomorphic instability (reaches are prone to accelerated and/or inappropriate patterns or rates of planform change and/or bank and bed erosion). • Excessively high volumes of coarse bedload which blanket the bed, reducing flow diversity. • Absent or geomorphically ineffective coverage by vegetation relative to the reference reaches (allowing most locations to have accelerated rates of erosion) or the reach is weed infested.

Table 21 Potential generic geomorphic responses to open cut mining-related causes.

Potential geomorphic response (event type)	Mining-related risks (see below for explanation)
1. Change in stream type, irreversible over management time scales (< 100 years)	1, 2
2. Change of alignment of channel	2
3. Simplification of channel morphology and habitat-scale hydraulics	2
4. Increase in sediment accumulation in channel bed	4, 5
5. Increase in sediment scouring in channel bed	3, 5
6. Increase in rate, or change in location, of bank erosion	5
7. Increase in rate of floodplain scour	3

Open cut mining related causes:

1. Removal of part or all of a stream channel and its catchment due to excavation of pit
2. Stream diversion construction to replace removed stream channel
3. Loss of active floodplain area due to excavation of pit
4. Decrease in stream flow due to artificially reduced catchment area
5. Increase in stream flow due to artificially increased catchment area

2.7.2 Indicators of risk of geomorphic change

The surface water assessment undertaken by WRM Water & Environment (2020) included design of mine site water management, as well as modelling the impact of the Project on hydraulic characteristics (water depth, velocity, and bed shear stress) of flood hydrographs for the main watercourses in the vicinity of the CQC Project area. These hydraulic characteristics were of interest to this report, as they condition sediment transport, and bed and bank erosion processes.

The modelling was run for flood events covering a range of recurrence intervals for the Existing scenario and the Developed scenario Project Stage 2, Mine plan representative year 8, representing the modelled period 2026-2029 (scenario P8).

The model was run for 114 climate sequences, each referred to as a “realisation”. Each realisation was based on an 18-year sequence extracted from the historical rainfall data. The first realisation was based on rainfall data from 1889 to 1906. The second used data from 1890 to 1907 and so on. Statistical analysis of the results from all realisations provided probability distributions of key hydrologic parameters (WRM Water & Environment, 2020).

In this report, the risk of geomorphic change was indicated by comparison of Existing and Developed (P8) scenario spatial distributions of the maximum of bed shear stress and velocity for the 10% AEP and 1% AEP event hydrographs. The magnitude of the distributions, and the differences in the magnitude of the distributions between Existing and Developed (P8) scenarios were used to locate areas of potential erosion risk that were then considered for mitigation and monitoring. Erosion risk was assessed on the basis of the maximum permissible velocity and bed shear stress categories established for streams and floodplains in the Project area (Table 18).

3.0 Existing environment

3.1 Landscape-Scale Characteristics

3.1.1 Catchment topography

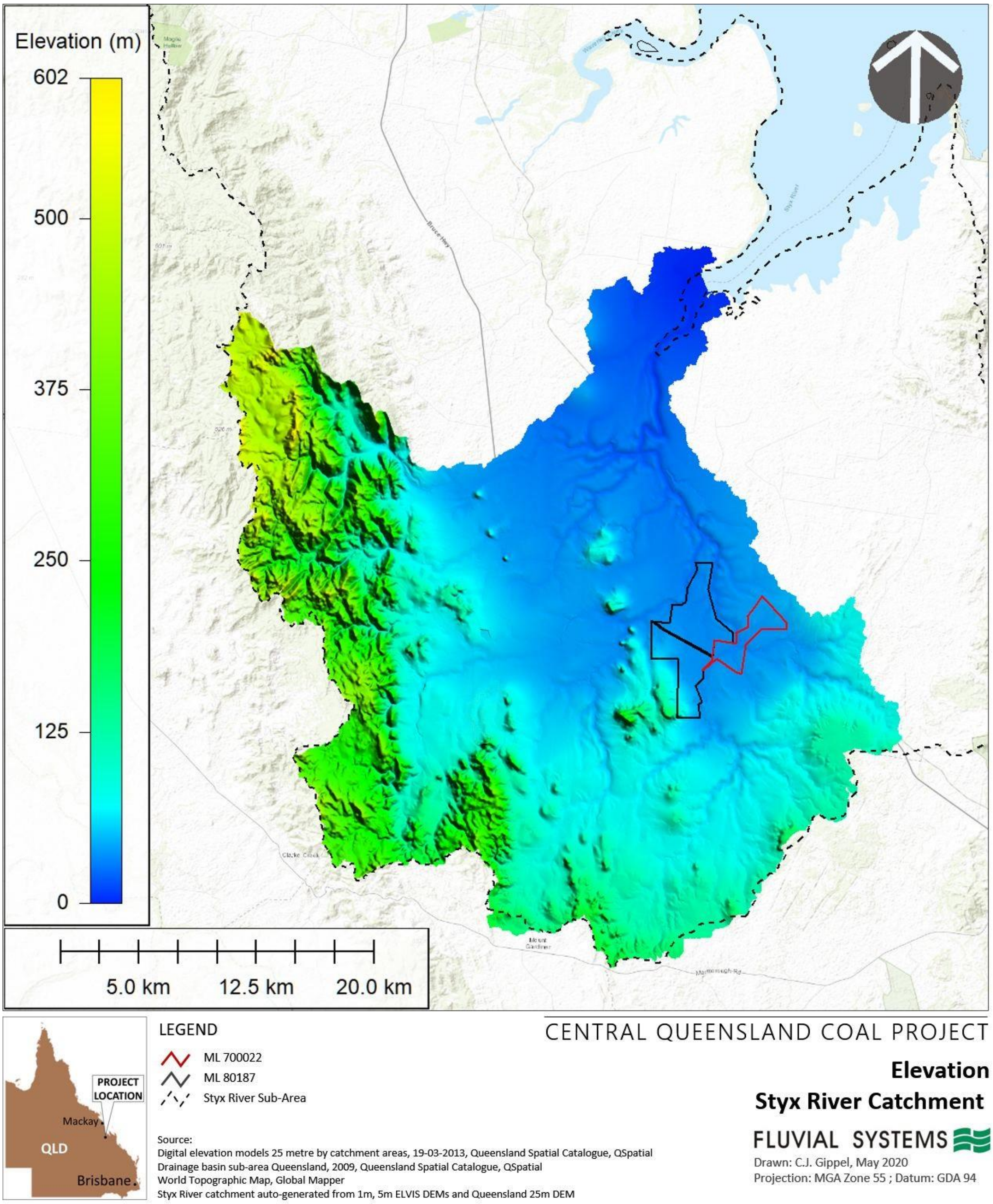
The CQC Project area lies within the Styx River Sub-area of the Fitzroy Drainage Division. In this report, the Styx River catchment was defined as the part of the Styx River Sub-area draining directly to the upper estuary, a total area of 1,093 km^2 (Figure 4). The Styx River catchment area defined automatically from the DEMs had a slightly different boundary to that defined by the Styx River Sub-area. Within this catchment, land surface elevation ranges up to 602 mAHD. The main area of interest, the CQC Project area, lies manly within the lowland topographic zone of the catchment, with an elevation range up to 249 mAHD (Figure 5).

3.1.2 Drainage system and sub-catchments

The Styx River is an Order 7 watercourse where it enters the estuary (Figure 6). The catchment has a high stream density in the western headwater area. The lowland zone, in which the CQC Project area is situated, has moderate to low stream density (Figure 6). Of the main streams in this catchment, in their lower reaches, Tooloombah Creek and Deep Creek are Order 6, and Barrack Creek is Order 5 (Figure 6 and Figure 7). The majority of the Styx River catchment comprises the sub-catchments of Tooloombah Creek/Mamelon Creek, Deep Creek/Barrack Creek, Montrose Creek and Granite Creek (Figure 7). In the lowland area, smaller tributaries drain directly to Styx River. The CQC Project area, situated on the interfluve between Tooloombah and Deep creeks, was drained by a system of minor creeks (Figure 8). The majority of this land drained to Deep Creek downstream of Barrack Creek junction (Figure 8).

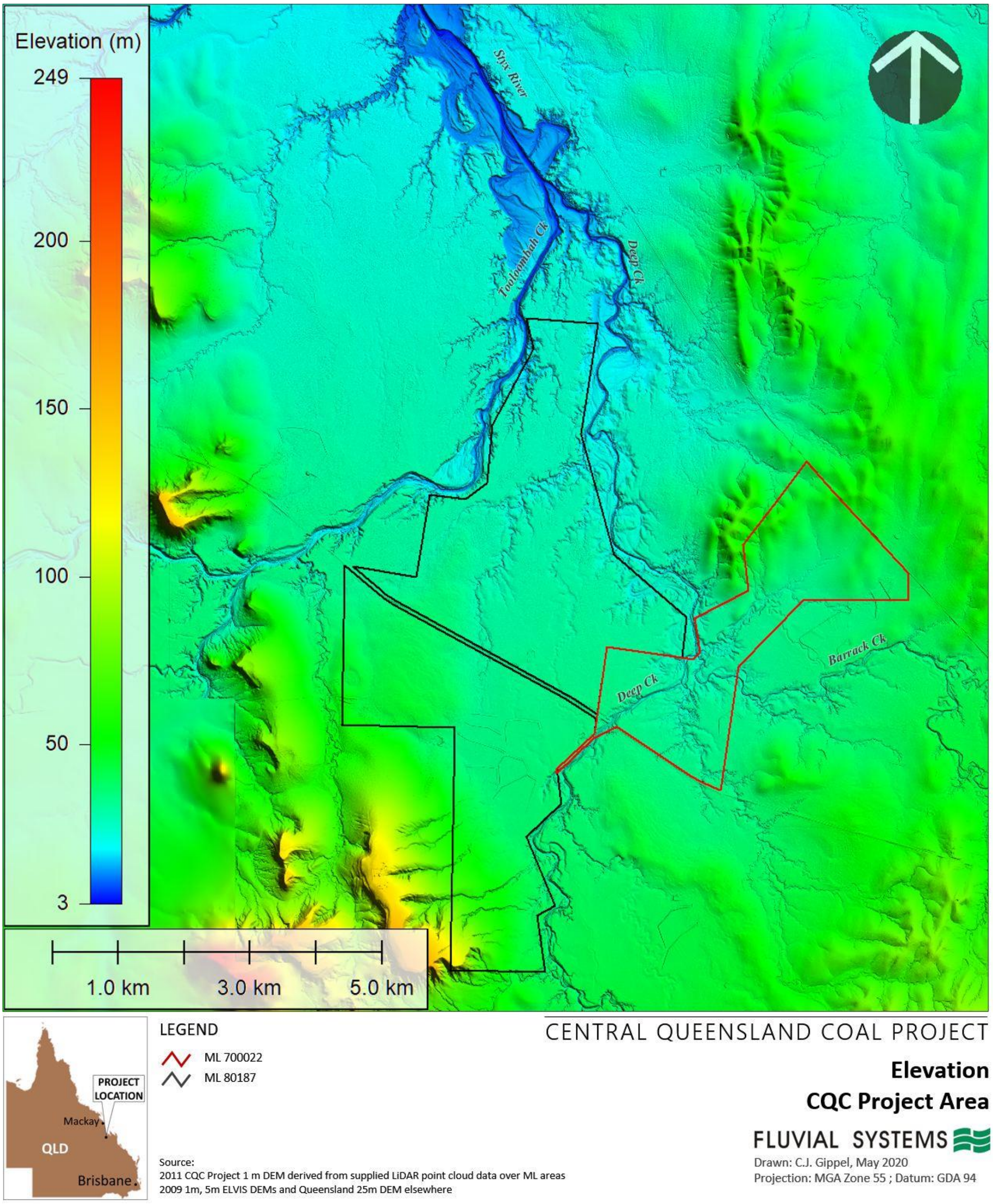
The larger mapped watercourse lines were in general agreement with the auto-generated drainage lines, although there were differences in detail (Figure 8). On the other hand, the alignments of some Order 1 and 2 streams in the Styx River catchment differed significantly from the auto-generated drainage lines. Some of these watercourses had been captured and diverted by farm dams and other obstructions that were constructed since the time of the original mapping.

A ubiquitous feature of the Styx River drainage system is channel incision. Tooloombah Creek and Deep Creek are both incised, and downstream of their junction, Tooloombah Creek/Styx River flows through an incised belt up to approximately 1 km wide (Figure 5). All of the small tributaries draining to the main watercourses are also incised (Figure 5).



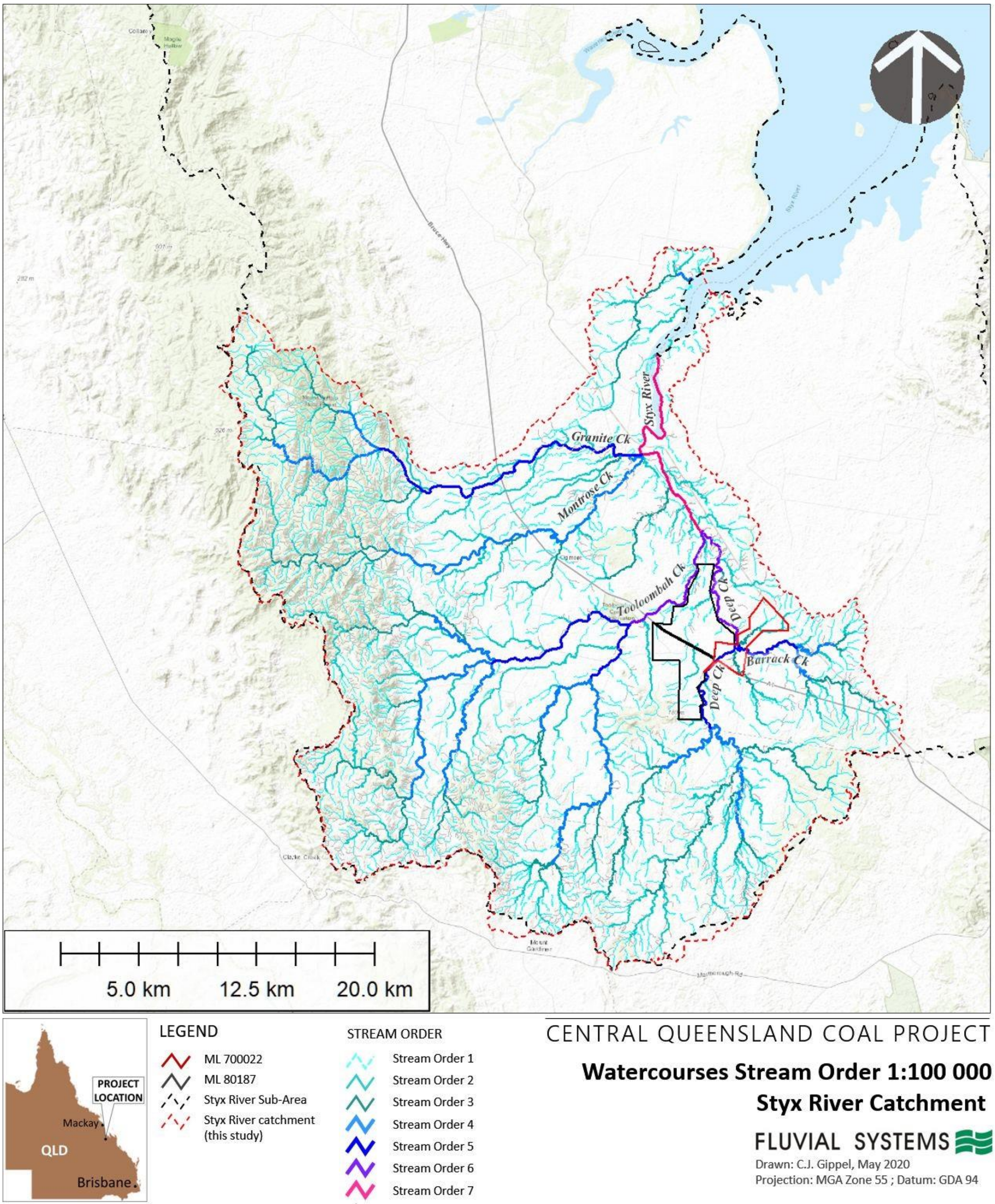
Source:
Digital elevation models 25 metre by catchment areas, 19-03-2013, Queensland Spatial Catalogue, QSpatial
Drainage basin sub-area Queensland, 2009, Queensland Spatial Catalogue, QSpatial
World Topographic Map, Global Mapper
Styx River catchment auto-generated from 1m, 5m ELVIS DEMs and Queensland 25m DEM

Figure 4. Styx River catchment topography.



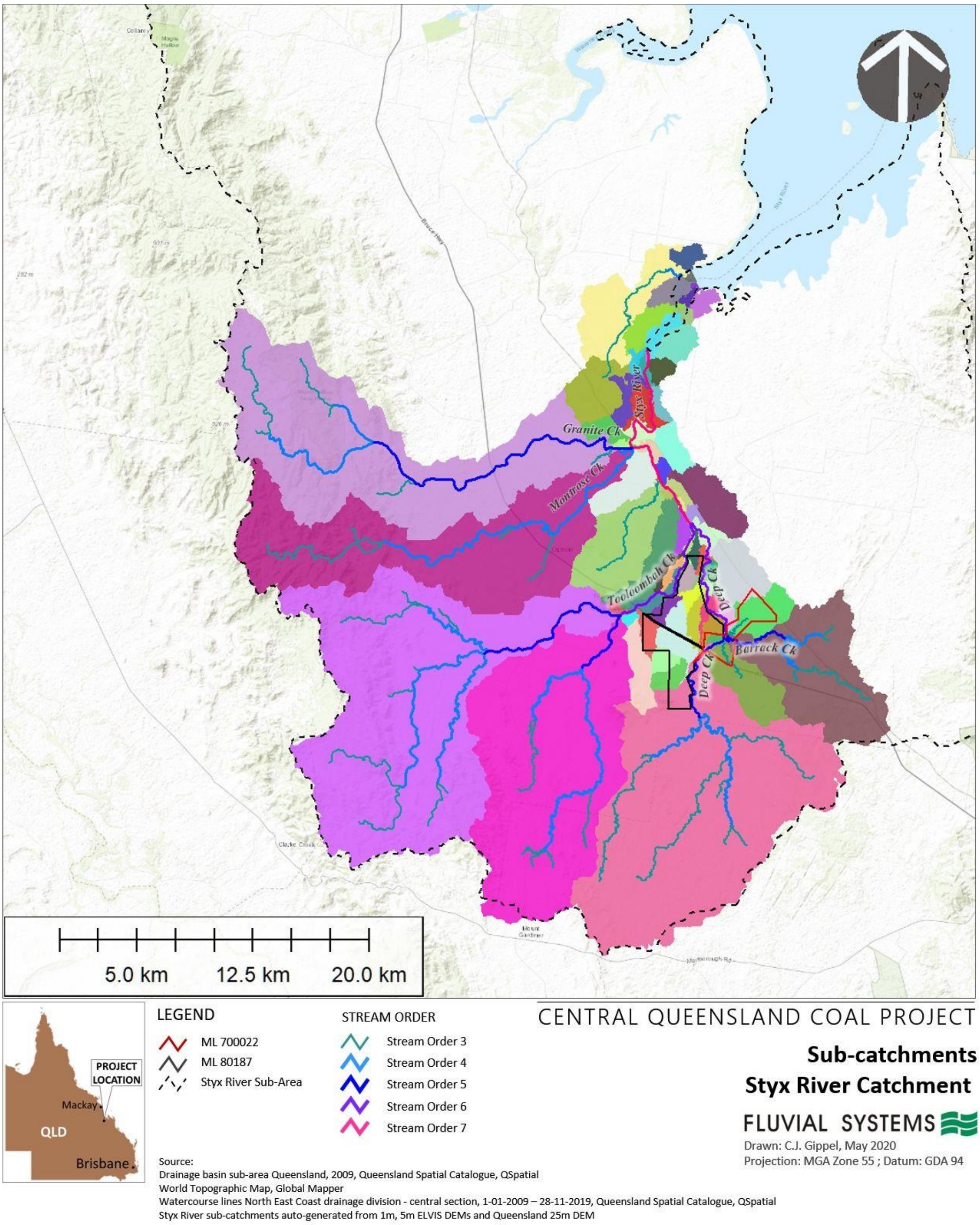
Source:
2011 CQC Project 1 m DEM derived from supplied LiDAR point cloud data over ML areas
2009 1m, 5m ELVIS DEMs and Queensland 25m DEM elsewhere

Figure 5. CQC Project area topography.



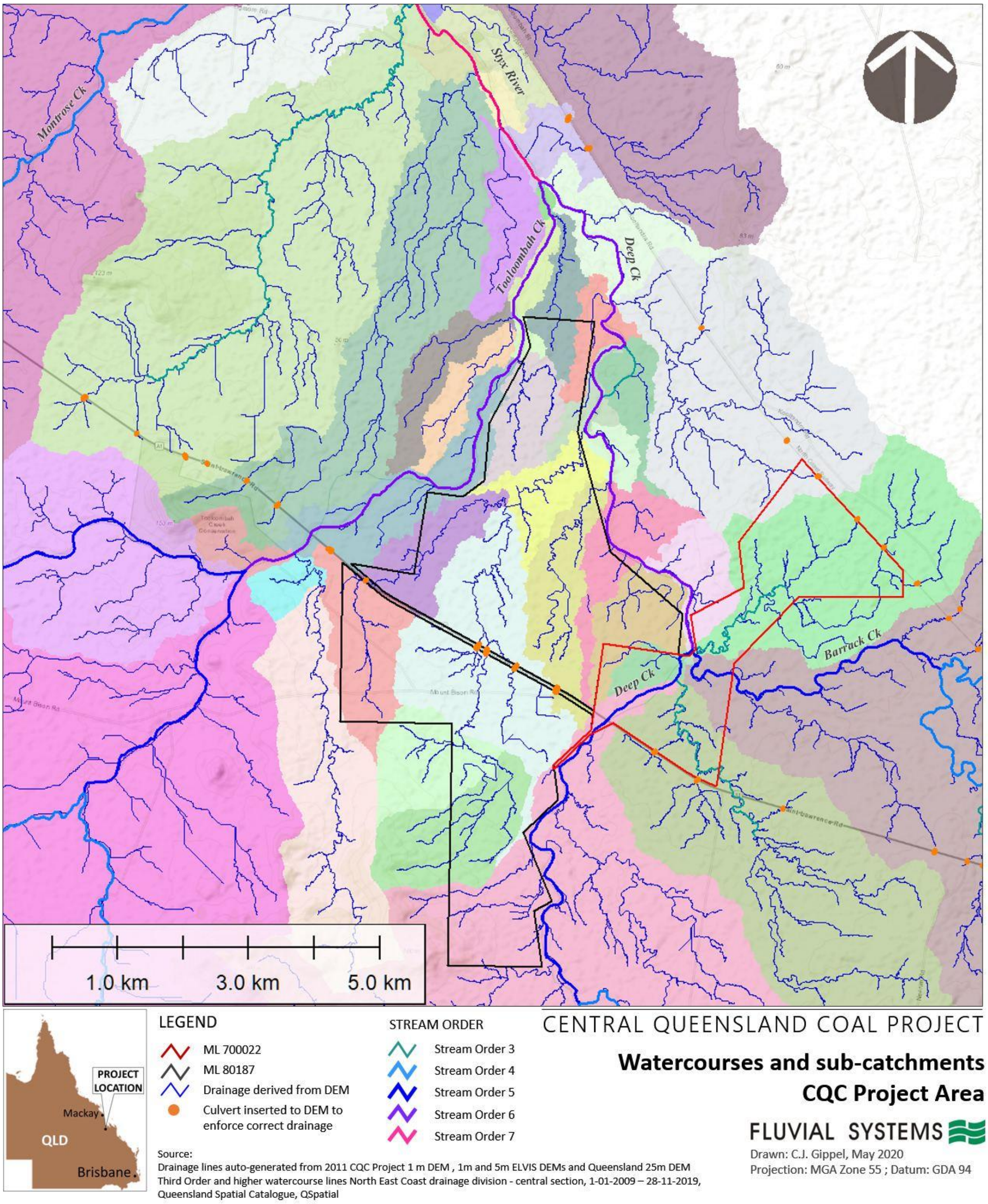
Source:
Watercourse lines North East Coast drainage division - central section, 1-01-2009 – 28-11-2019, Queensland Spatial Catalogue, QSpatial
Drainage basin sub-area Queensland, 2009, Queensland Spatial Catalogue, QSpatial
World Topographic Map, Global Mapper
Styx River catchment auto-generated from 1m, 5m ELVIS DEMs and Queensland 25m DEM

Figure 6. Styx River catchment Watercourses and Stream Order.



Source:
Drainage basin sub-area Queensland, 2009, Queensland Spatial Catalogue, QSpatial
World Topographic Map, Global Mapper
Watercourse lines North East Coast drainage division - central section, 1-01-2009 – 28-11-2019, Queensland Spatial Catalogue, QSpatial
Styx River sub-catchments auto-generated from 1m, 5m ELVIS DEMs and Queensland 25m DEM

Figure 7. Styx River catchment main watercourse sub-catchments.



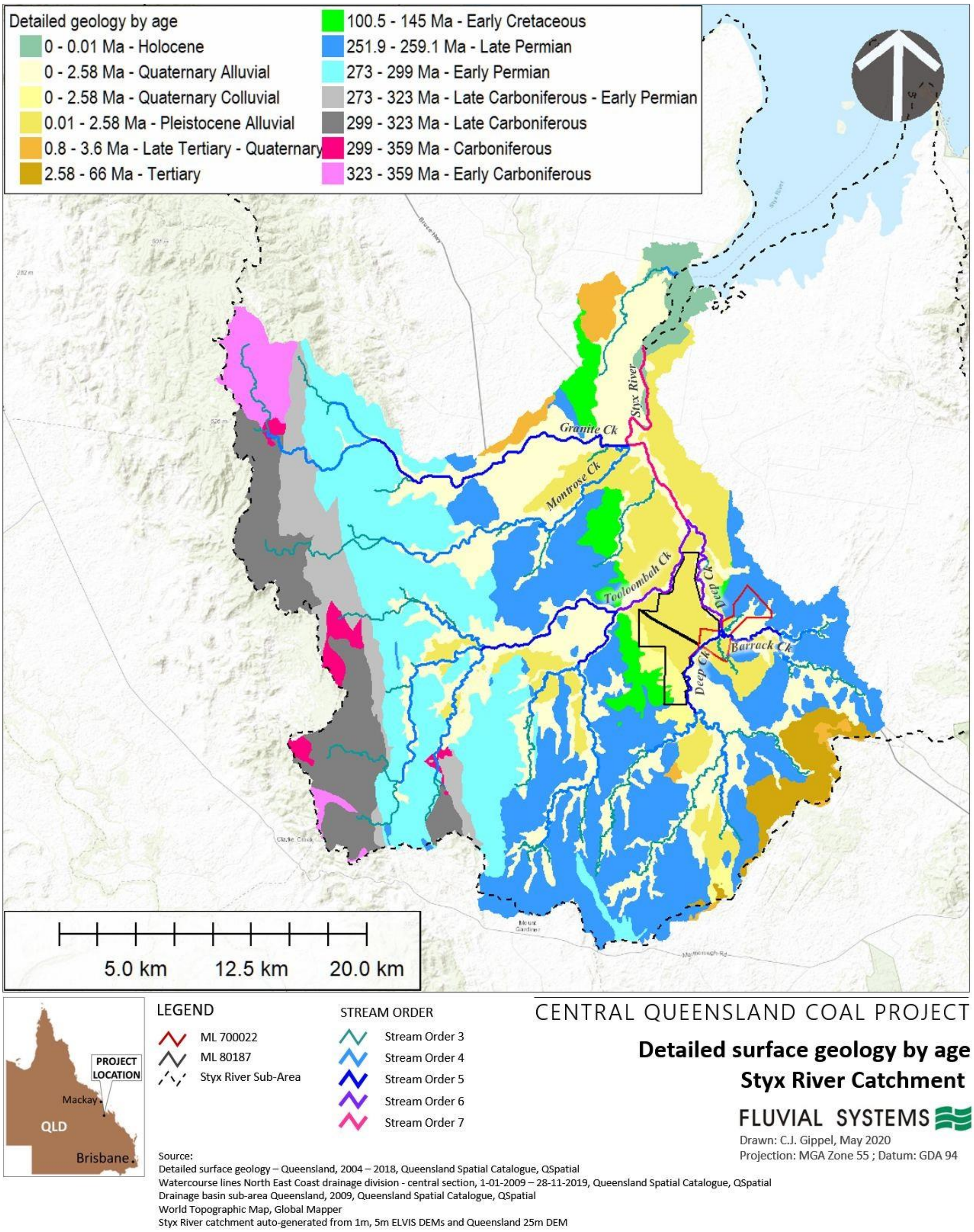
Source:
Drainage lines auto-generated from 2011 CQC Project 1 m DEM , 1m and 5m ELVIS DEMs and Queensland 25m DEM
Third Order and higher watercourse lines North East Coast drainage division - central section, 1-01-2009 – 28-11-2019, Queensland Spatial Catalogue, QSpatial

Drawn: C.J. Gippel, May 2020
Projection: MGA Zone 55 ; Datum: GDA 94

Figure 8. CQC Project area watercourses and sub-catchments.

3.1.3 Geological classification

The geology of the Styx River catchment is characterised as Holocene sediments in the estuary, with vast areas of Quaternary alluvial deposits overlying the early Cretaceous Styx Coal Measures, the strata of which consists of quartzose, calcareous, lithic and pebbly sandstones, pebbly conglomerate, siltstone, carbonaceous shale and coal (CDM Smith, 2017; 2018). The Styx Coal Measures overly a progression of Late Carboniferous to Late Permian deposits (Figure 9). Alluvial lithological units Qpa and Qa dominate the CQC Project area (Figure 10) with Holocene Qh sediments also occurring in the estuary (Figure 11).



Source:
Detailed surface geology – Queensland, 2004 – 2018, Queensland Spatial Catalogue, QSpatial
Watercourse lines North East Coast drainage division - central section, 1-01-2009 – 28-11-2019, Queensland Spatial Catalogue, QSpatial
Drainage basin sub-area Queensland, 2009, Queensland Spatial Catalogue, QSpatial
World Topographic Map, Global Mapper
Styx River catchment auto-generated from 1m, 5m ELVIS DEMs and Queensland 25m DEM

Figure 9. Detailed surface geology of the Styx River catchment by age.

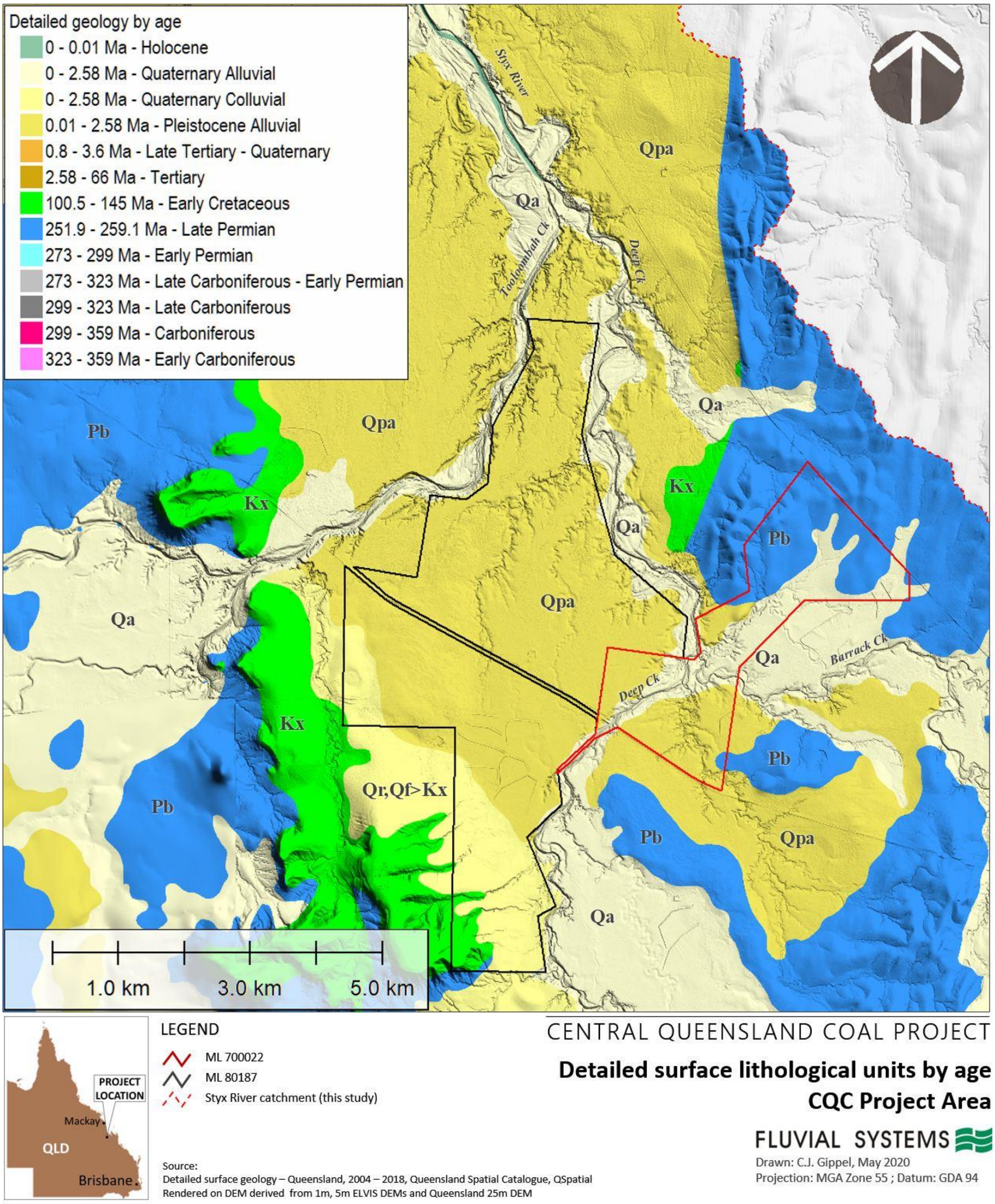


Figure 10. Detailed surface geology of the CQC Project area by age.

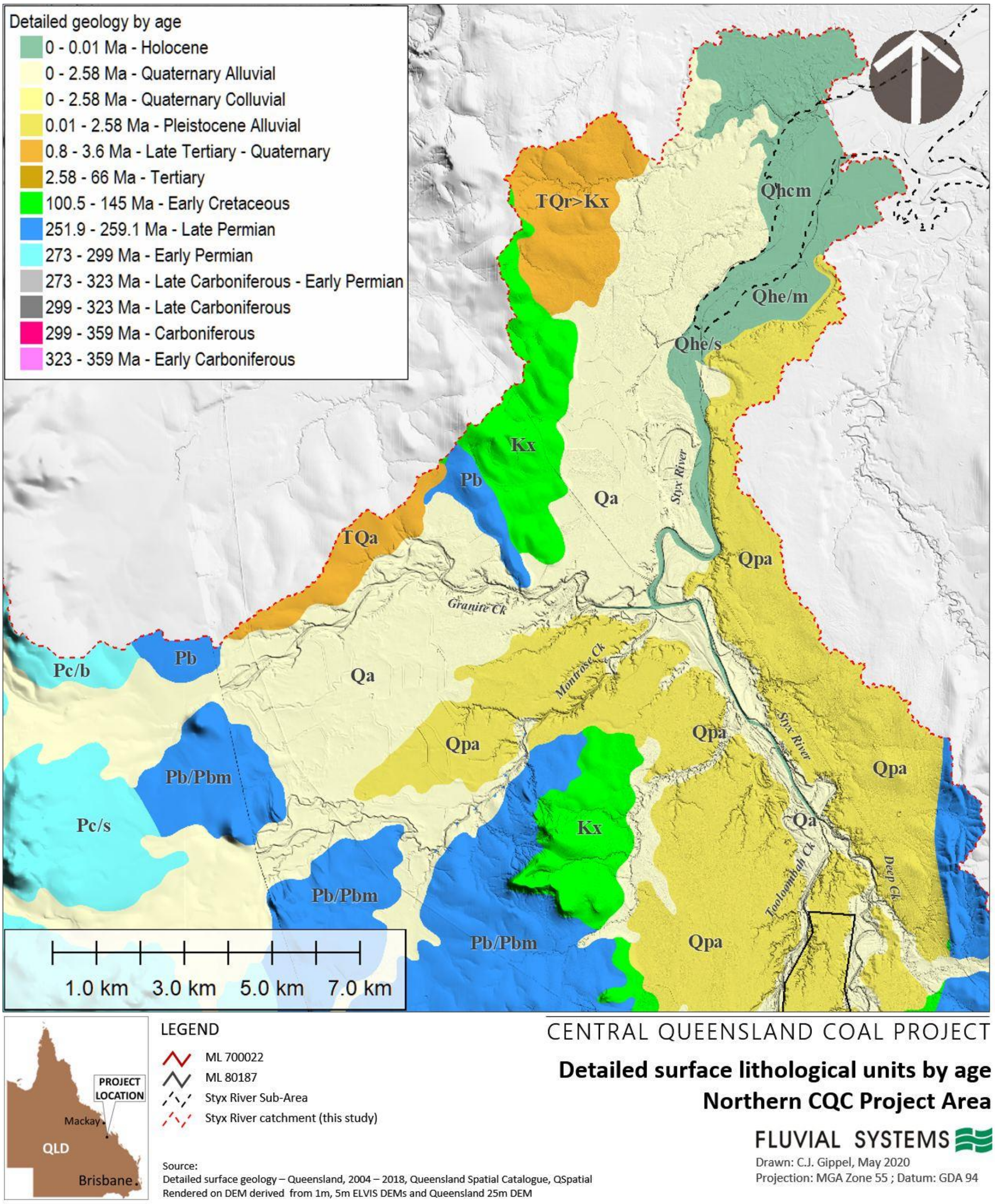


Figure 11. Detailed surface geology of the northern CQC Project area by age.

3.1.4 Geomorphology of alluvium in the Styx River valley

Alluvium is eroded material that has been transported far from its source and deposited by a stream in a valley floor. ‘Unconsolidated’ alluvium is a permeable deposit of sand and gravel that could contain alluvial aquifers, while ‘consolidated’ alluvium is a deposit of silt and clay with low permeability, and little prospect for containing alluvial aquifers. Floodplains are by definition composed of alluvium, but alluvium does not always contain aquifers with significant reserves of groundwater. In this report, ‘alluvium’ is meant in the geomorphic sense, and should not be interpreted to mean ‘alluvial aquifer’.

All of the alluvium in the Styx River valley was formed within the Quaternary Period (2.58 million years ago to the present day) of the Cainozoic Era (66 million years to the present day). The Quaternary Period comprises the Pleistocene (2.58 million years ago to 11,700 years ago) and Holocene (11,700 years to the present day) epochs.

Alluvium in the Styx River valley has been classified and mapped according to geological age in the digital layer Detailed surface geology – Queensland (Department of Natural Resources, Mines and Energy, 2019). The boundaries of Qpa (Pleistocene), Qa (undifferentiated Quaternary) and Qhe (Holocene) units were mapped at a relatively coarse scale (1:100,000, but derived from 1:250,000 map sheets and other data) (Figure 9, Figure 10 and Figure 11).

There were two main periods of Quaternary alluvial deposition in coastal streams within alluvial valleys. The first was responsible for formation of the Qpa terraces that bound the rivers of the region, while the second was responsible for formation of the Qa benches and inset floodplains that are found within the macro-channel formed in Qpa sediments.

The Upper Pleistocene sub-epoch occurred 11,700 – 130,000 years ago. During the early interglacial part of the Upper Pleistocene, 130,000 – 119,000 years ago, sea levels were 4 – 6 metres higher than present (Wilson and Taylor, 2012) (Table 22). What is now the current coast line would have been submerged, with estuarine deposits forming further inland than currently. The onset of glaciation resulted in decline of sea levels. Near the coast, rivers would have incised into previously deposited alluvium. The glacial cycle peaked 21,000 years ago, when the sea level was around 125 m lower than present (Table 22). The latter part of the glacial cycle was coincident with the development of vast alluvial plains that form the current Qpa terraces. The main depositional phase started around 30,000 years ago and ceased around 9,000 years ago (Table 22).

The Holocene Epoch occurred over the past 11,700 years. Lambeck and Nakada (1990) suggested that present sea-level was reached about 6,000 years ago, but this date has been revised to 7,700 years (Table 22). A fluvially active period occurred around the time of the Holocene Climate Optimum (HCO), 6,000 – 9,000 years ago, resulting in the relatively rapid incision of a macro-channel into Qpa sediment. Tributaries would have incised into the Qpa in response to base level lowering of the main river channels. This period of incision was followed by the second main period of alluvial deposition which involved development of Holocene-age benches and inset floodplains within the macro-channel (Table 22). Despite this being a depositional phase, knickpoints on steepened, incised tributaries might have continued to progress upstream. In estuarine areas, alluvium was reworked to produce Qhe morphology (Table 22).

On the West Normanby River at Kings Plains, located in the Wet Tropics of north Queensland, Pietsch et al. (2015) determined that the alluvial terrace was built through the Upper Pleistocene and into the Holocene, with approximately 10 m of medium to coarse sands laid down between 33,000 and 16,400 years ago, and the upper two metres dating to 8,760 years ago. At the sampled sites, the surface of the Pleistocene terrace was around 25 – 30 m above the current channel thalweg. The surfaces of inset Holocene benches were at various elevations within and between sites, mostly within the range 3.5 to 10 m above the channel thalweg (Pietsch et al., 2015).

In the Styx valley, Detailed surface geology – Queensland (Department of Natural Resources, Mines and Energy, 2019) maps Holocene-age alluvium variants Qhe/s, Qhe/m and Qhcm (Figure 11). These are all estuarine sediments. Qha is not mapped in the Styx valley. Rather, within the macro-channel, where Qha would be expected, the unit is labelled Qa (undifferentiated) with lithology described as clay, silt, sand, gravel; floodplain alluvium. Undifferentiated means that it was not possible to specify finer age divisions. Qa potentially comprises active Holocene alluvium (Qha) and Upper Pleistocene alluvium (Qpa). In the Styx valley, Detailed surface geology – Queensland (Department of Natural Resources, Mines and Energy, 2019) described the lithology of Pleistocene-age Qpa as clay, silt, sand, gravel; flood-plain alluvium on high terraces. The only lithological difference with Qa is reference to its occurrence on high terraces.

Soil developed from Pleistocene alluvium commonly has a higher degree of profile development than that developed from Holocene alluvium (Wilson and Taylor, 2012). However, these landscapes often grade into each other, making it difficult to distinguish a hard boundary for the purpose of geological mapping. In some places, the Pleistocene alluvium can be inundated by flood events from creeks draining the local uplands (Wilson and Taylor, 2012). Also, the depositional phase that built the Qpa terraces continued into the early part of the Holocene, so the upper layers of the terrace do not necessarily belong to the Pleistocene epoch. Although Holocene alluvium is found within a macro-channel, the morphology of this channel can be complex, with multiple channels dissecting through the terrace. Together, these difficulties with boundaries and classification have led to the currently active river corridor falling within a zone mapped Qa (undifferentiated).

Table 22. Quaternary history and fluvial geomorphic response.

Period	Epoch	Sub-epoch	Stage/climate	Sea level	Channel morphology
Quaternary	Holocene <11,700 years		0 – 2,000 years	Declining to present level[1]	Development of modern Qa units within the macro-channel formed in Qpa[2]. In estuarine areas, alluvium was reworked to produce Qhe morphology. Deposition and erosion cycles reworked alluvium according to sea level variation (deposition in the highstands), climatic change, periods of drought and flood dominance, plus human influence on catchment and riparian vegetation cover[3]. Gullies developed in upper tributaries, and alluvial gullies developed and expanded on main channels[4]. -
			2,000 – 3,500 years; sharp decline in precipitation and increased climatic variability 3,700 – 1900 years[5]	Within 0.5 m of present[6]; evidence for an oscillation 2,000 – 2800 years[7]	
			Highstand 4,000 – 7,000 years; wetter during HCO, then becoming drier after 5,000 years[8]	1.5 – 2.0 m higher than present[9]	
			7,700 years	Approximately the same as present[10]	
			Holocene Climate Optimum (HCO); 6,000 – 9,000 years wet, warm climate period[11]	Lower than present[12]	Incision and abandonment of Qpa terraces occurred in the Qld Wet Tropics 6,000 – 19,000 years[13] and 8,000 – 13,000 years[14]; in SEQ (Lockyer, Logan, Albert, Brisbane rivers) 7,500 – 10,800 years[15]; in Bellinger River (mid-north coast NSW) 4,500 – 10,000 years[16]; possibly rapid terrace abandonment[17]
	Pleistocene 11,700 – 2.58 M years	Upper Pleistocene 11,700 – 130,000 years	Meltwater Pulse 1A, coinciding with the Bølling warming event 14,650 years[18].	Rapid sea-level rise began	Ongoing deposition of Qpa.
			Last Glacial Maximum (LGM) 21,000 years[19]. Coincided with a period of significantly reduced rainfall in NE Australia 19,000 – 23,000 years[20].	Around 125 m lower than present	Base-level lowering led to incision of old Qpa on coastal margin[21]. Deposition of existing Qpa terraces occurred in the Qld Wet Tropics, 14,000 – 27,000 years ago[22]; Nogoa and Fitzroy 11,000 – 30,000 years ago[23]; Normanby River 8,760 – 33,000 years ago[24]
			Last inter-glacial high-stand, within the Marine Isotope Stage (MIS) 5e 119,000 – 130,000 years	Approximately 4 – 6 m higher than present[25]	Deposition of old Qpa in coastal areas.
		Middle and lower Pleistocene 130,000 – 2.58 M years	Around 50 glacial cycles[26]	Alternating lower and sometimes higher than present[27]	Erosion and deposition cycles of old Qpa

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[1] See Lewis et al. (2008).
[2] See Pietsch et al. (2015).
[3] See Leonard and Nott (2016).
[4] See Brooks et al. (2007), Brooks et al. (2009), Brooks et al. (2013),
[5] Sloss et al. (2018) cited <3,500 years for southern Gulf of Carpentaria; a date of 2,000 years was cited by Lewis et al. (2008) for eastern Australia.
[6] See Sloss et al. (2018).
[7] See Lewis et al. (2008).
[8] See Sloss et al. (2018).
[9] See Sloss et al. (2018). Lewis et al. (2008) cited a highstand range of 1.0 – 1.5 m. Dougherty et al. (2019) provided evidence to support a highstand with earliest date approx. 7,000 years, synchronous over an area that extended from the Gulf of Carpentaria to Tasmania.
[10] See Sloss et al. (2018).
[11] See Cohen and Nanson (2007). Leonard and Nott (2016) cited evidence that increased rainfall persisted from the end of the LGM (18,000 years) until 6,000 – 8,000 years. The climate was drier from 6,000 years (Cohen and Nanson, 2007).
[12] See Sloss et al. (2018).
[13] See Leonard and Nott (2016).
[14] See Hughes and Croke (2017).
[15] See Daley and Cohen (2018).
[16] See Cohen and Nanson (2008).
[17] Increased precipitation-driven terrace abandonment may have been associated with extreme events and may well have occurred rapidly (Daley and Cohen, 2018).
[18] See Brendryen et al. (2020). A range of 14,300 – 14,600 years was suggested by Lewis et al. (2013).
[19] See Williams et al. (2018) and Ulm et al. (2018). A range of 17,000 – 19,000 years according to references cited by Ludt and Rocha (2014). A range of 19,000 – 21,000 years according to Lewis et al. (2013). The lowest sea level varies within the literature, but 125 m is often cited.
[20] See Leonard and Nott (2015).
[21] See Wilson et al. (2012). Trenching of Qpa in response to lowering base-level (i.e. sea level) would apply in close proximity of the coast.
[22] See Leonard and Nott (2016), Hughes and Croke (2017),
[23] See Croke et al. (2011).
[24] See Pietsch et al.(2015), dates from 12 m exposure of a terrace 27 m above the channel of the West Normanby River at Kings Plains.
[25] See Wilson et al. (2012) and Gornitz (2007). Also, reported for tectonically-stable areas of the Southern Hemisphere, sea levels higher than present by 6.0 – 8.5 m (South Africa) (Carr et al., 2010), 7 m (southern Brazil) (Tomazelli and Dillenburg, 2007), 4 – 10 m (Western Australia) (Hearty et al. 2007, O'Leary et al., 2008), 2 – 6 m (southern Australia) (Murray-Wallace, 2002), 2 - 4 m (Eyre Peninsula) (Murray-Wallace and Belperio, 1991; Murray-Wallace et al., 2016), 1 m (Spencer Gulf) (Hails et al., 1984). See Hearty et al. (2007) for data from other areas. A probabilistic assessment by Kopp et al. (2018) found a 95% probability that global sea level peaked at least 6.6 m higher than present and 67% probability to have exceeded 8.0 m higher than present.
[26] See Woodruff (2010).
[27] See Spratt and Lisiecki (2016).

3.1.5 Land Systems

Across the Styx River catchment, although some Land Systems and surface geology lithological unit boundaries coincided, in general, Land Systems were only broadly related to geology (Figure 9 and Figure 12). Within the CQC Project area (Figure 13), Styx Land System coincided with Qa, but only when Qa was situated within Sommerby Land System. Styx Land System soils were described as brown, massive, fine sandy loams formed on narrow floodplains (Table 3). Sommerby and Blackwater are described as comprising Brigalow plains and cracking clay soils on weathered Tertiary clay (Table 3), yet these are located on Pleistocene Qpa geological units. Plainview and Tooloomba Land Systems occur over other areas of Qpa and Qa (Figure 13). These two Land Systems are similar, with both containing alkaline sodic duplex soils (Table 3).

3.1.6 Soil mapping by CDM Smith (2018b)

CDM Smith (2018b) undertook a preliminary desktop soils and landform assessment using: ASRIS 2011, which provides a general description of soils classified in accordance to the Australian Soil Classification (Isbell, 2002); the ‘Atlas of Australian Soils’ by CSIRO; Queensland Globe’s ASS distribution map which provides an indication of the likelihood of Acid Sulphate Soils (ASS) or potential ASS (PASS) being present, and; a review of site-specific soil sample records in the locality. CDM Smith (2018b) also undertook a field soil survey that included 11 soil auger sites (where detailed soil profile descriptions were made and samples were taken), 16 observation locations, and laboratory analysis.

Queensland soil maps indicate sodosols, vertosols and kandosols are the predominant soil orders within the CQC Project area. Vertosols correspond to the flatter landscape to the north, Sodosols are the most widespread soil order and correspond to the more elevated plains, while Kandosols correspond to the undulating land to the south west. CDM smith (2018b) found reasonable alignment between the soil orders mapped by desktop analyses and the soil classifications made by field investigations.

CDM Smith (2018b) reported that the CSIRO National ASS mapping described most of EPC 1029, which includes the CQC Project area, as having a low to extremely low probability of containing ASS.

3.1.7 Soil Map Units

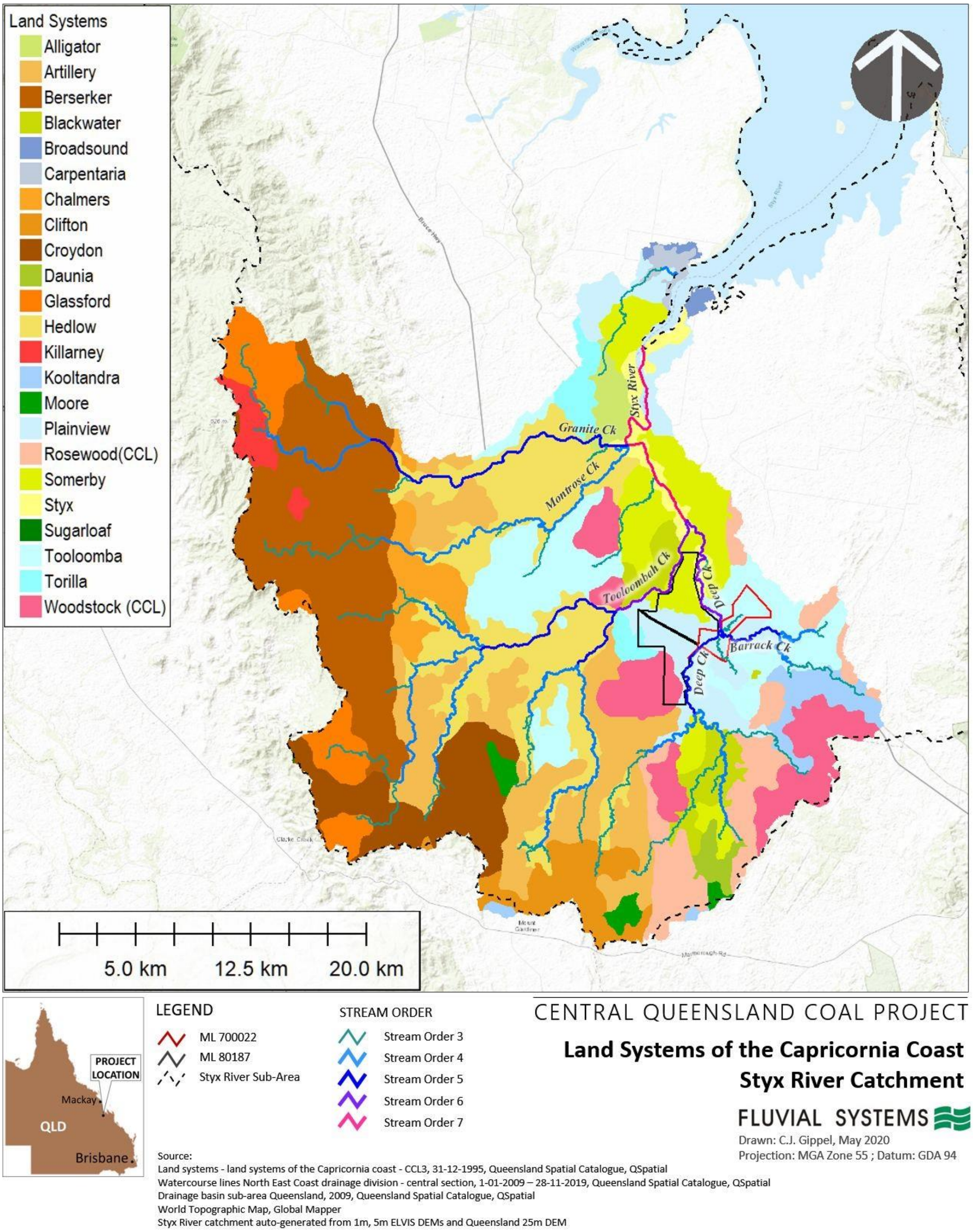
Soil Units were mapped by HESSE (2020) for the CQC Project area (Figure 14). The areas within the lease area plus a 300 m buffer were ground-truthed. Areas outside of this have lower confidence in the soil unit identification. The map of HESSE (2020) is similar to the map of CDM Smith (2018b, p. 5-35) based on ASRIS, 2011. The main differences relate to the distribution of Kandosols, which HESSE (2020) mapped in an area to the south east of the CQC Project area, in addition to the area to the south west, and HESSE (2020) including Alluvial soils.

Some of the boundaries of the Soil Units corresponded with mapped geological and Land Systems boundaries, but the coincidence was inconsistent. Shallow, gravelly alluvium occurred within the narrow geomorphically-active river beds. Non-gravelly alluvium occurred on Tooloomba Creek and Styx River terraces. Much of the CQC Project area within the mining lease boundaries is on Sodosols, described as sodic soils with contrasting topsoil and subsoil texture (Table 7).

3.1.8 Surface soil and overall inherent soil erodibility

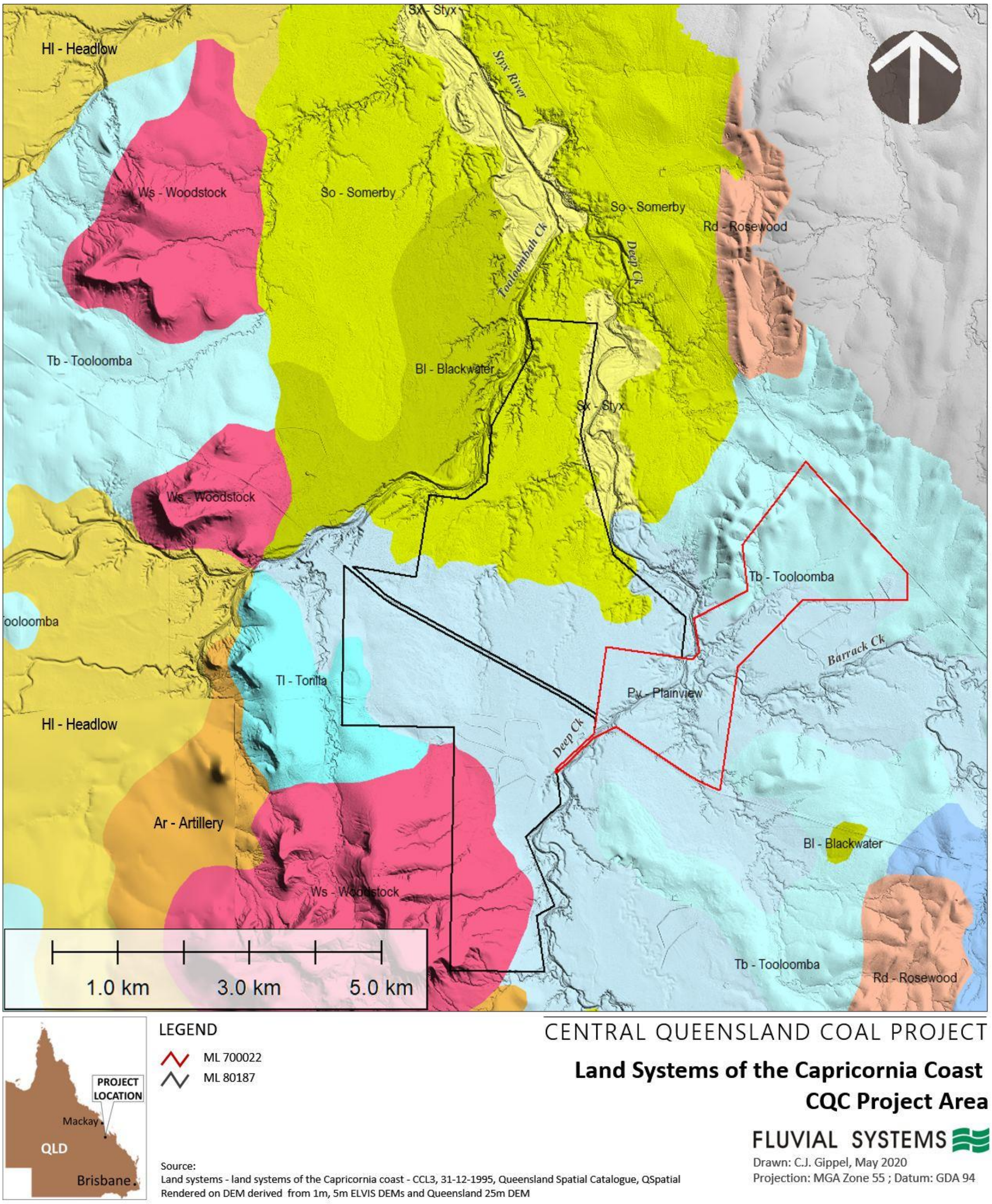
Soil erodibility is relevant to management of runoff from disturbed areas, and management of the surface condition of soils on disturbed areas. Over the Styx River catchment, soil surfaces tended to become more erodible towards the lowland area (Figure 15). Sodic, dispersible surface soils with high erodibility occurred over the majority of the CQC Project area (Figure 16). Barrack Creek in particular was located in an area of highly erodible surface soils.

The pattern of overall inherent soil erodibility was similar to that of surface soil erodibility. Overall inherent soil erodibility was stable in the headwater areas of the Styx River catchment, while in the lowland areas the soils were clayey and dispersive (Figure 17). As for surface soil erodibility, the overall inherent erodibility of soils over the CQC Project area was mapped high and very high vulnerability to erosion (Figure 18).



Source:
Land systems - land systems of the Capricornia coast - CCL3, 31-12-1995, Queensland Spatial Catalogue, QSpatial
Watercourse lines North East Coast drainage division - central section, 1-01-2009 – 28-11-2019, Queensland Spatial Catalogue, QSpatial
Drainage basin sub-area Queensland, 2009, Queensland Spatial Catalogue, QSpatial
World Topographic Map, Global Mapper
Styx River catchment auto-generated from 1m, 5m ELVIS DEMs and Queensland 25m DEM

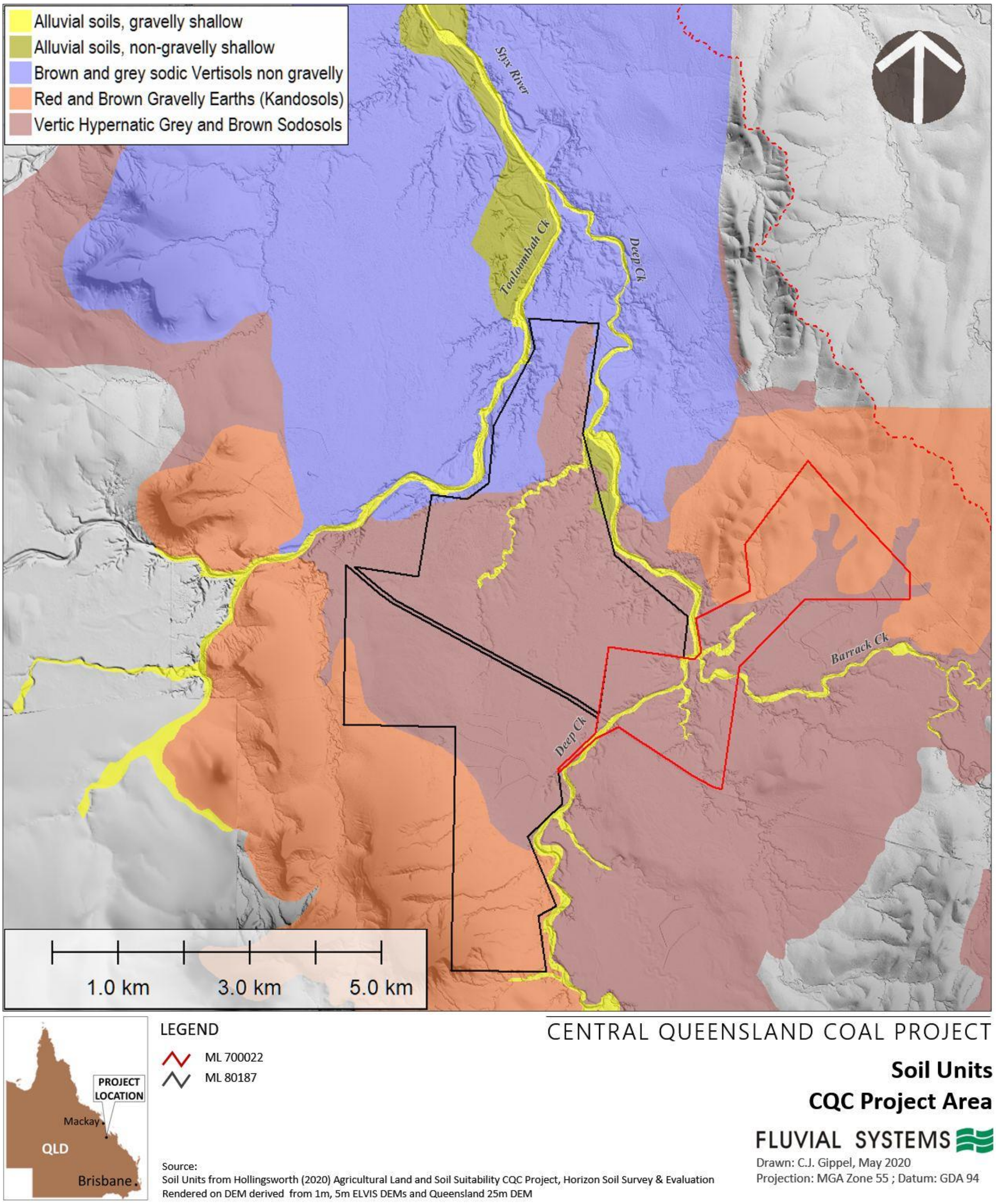
Figure 12. Land Systems of the Styx River catchment.



Source:
Land systems - land systems of the Capricornia coast - CCL3, 31-12-1995, Queensland Spatial Catalogue, QSpatial
Rendered on DEM derived from 1m, 5m ELVIS DEMs and Queensland 25m DEM

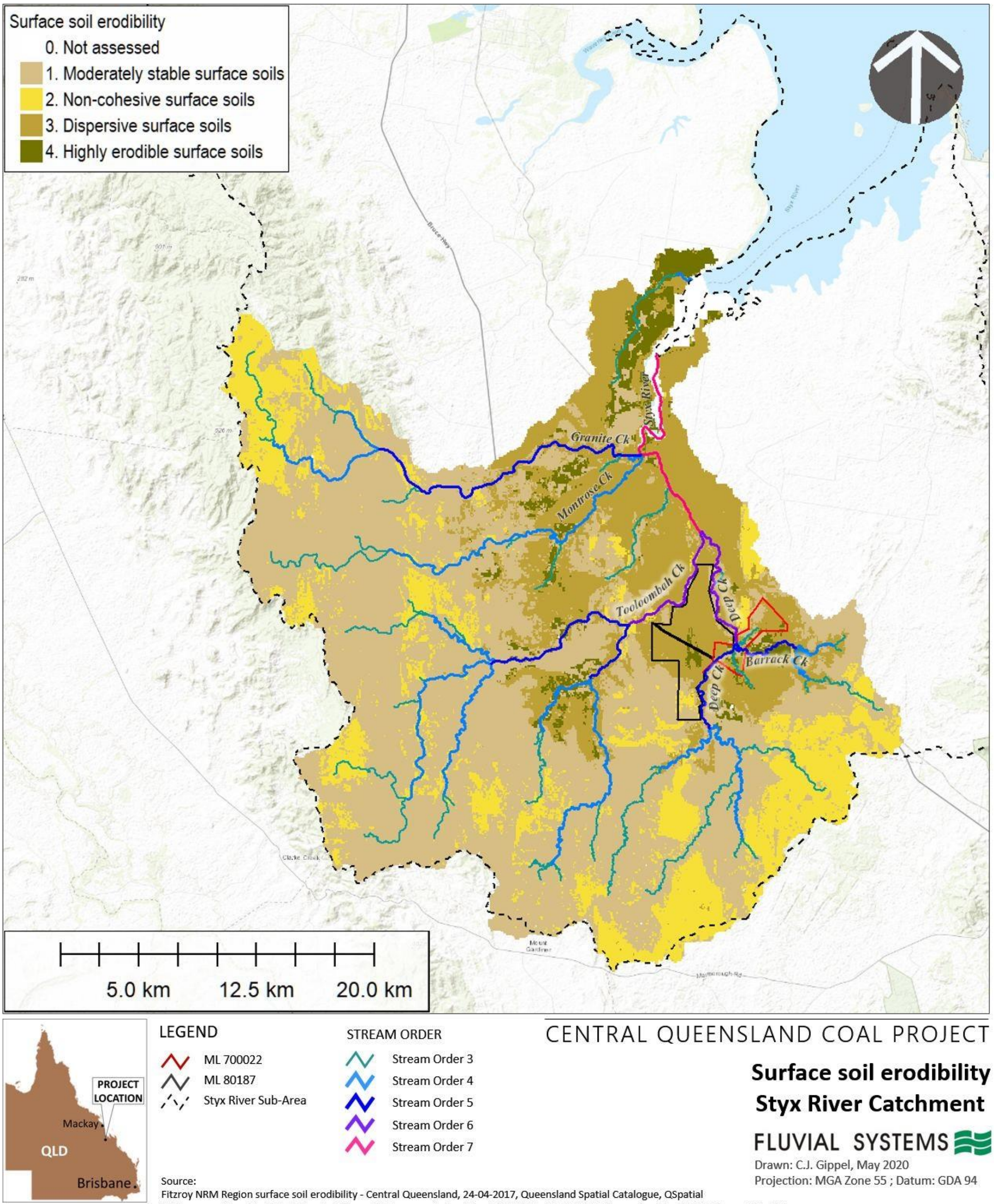
Drawn: C.J. Gippel, May 2020
Projection: MGA Zone 55 ; Datum: GDA 94

Figure 13. Land Systems of the CQC Project area.



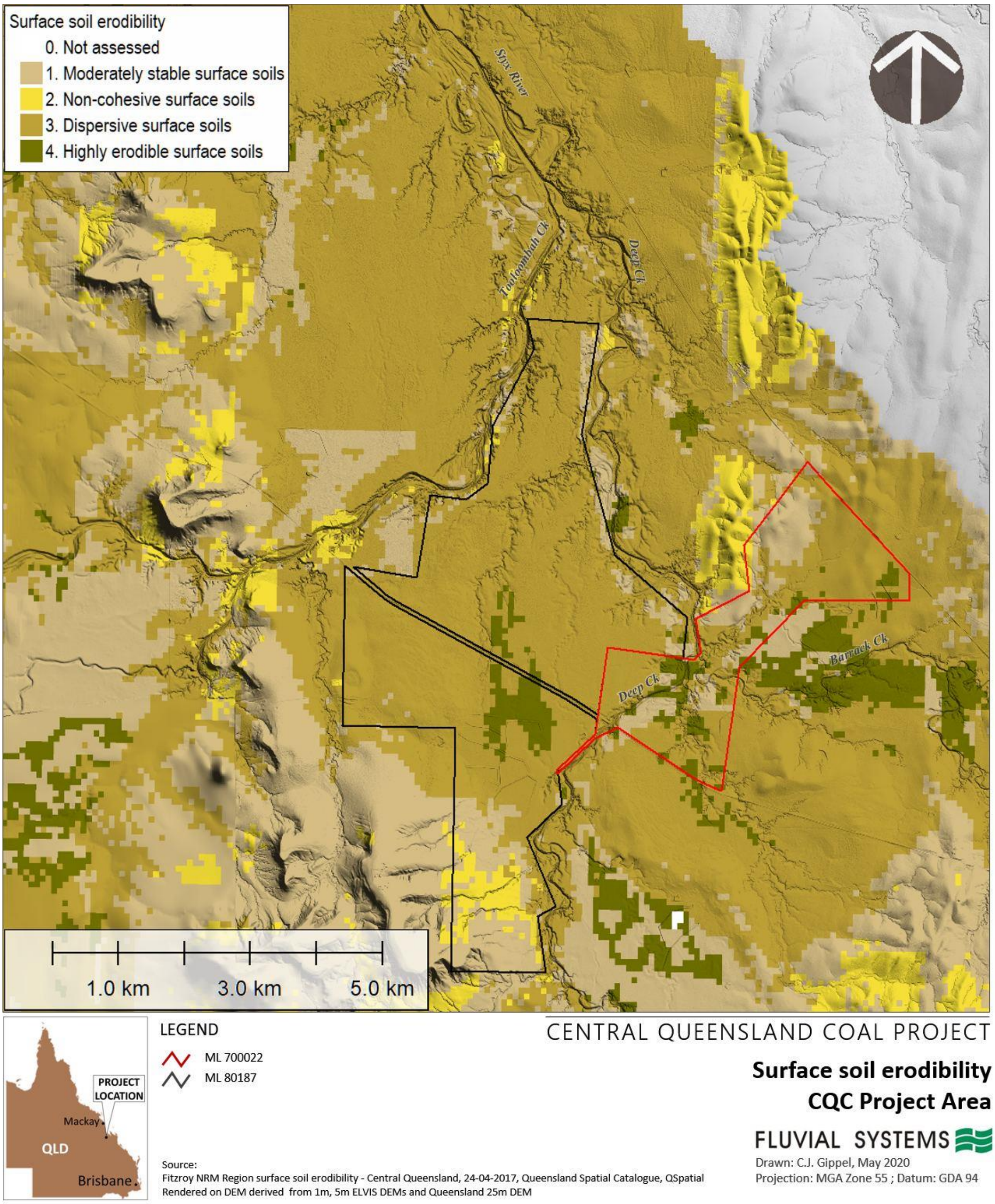
Source:
Soil Units from Hollingsworth (2020) Agricultural Land and Soil Suitability CQC Project, Horizon Soil Survey & Evaluation
Rendered on DEM derived from 1m, 5m ELVIS DEMs and Queensland 25m DEM

Figure 14. Soil Units mapped by HESSE (2020) over the CQC Project area. Note: The area inside the lease area plus a 300 m wide buffer was ground-truthed. Outside of this area the soil unit identification has lower confidence.



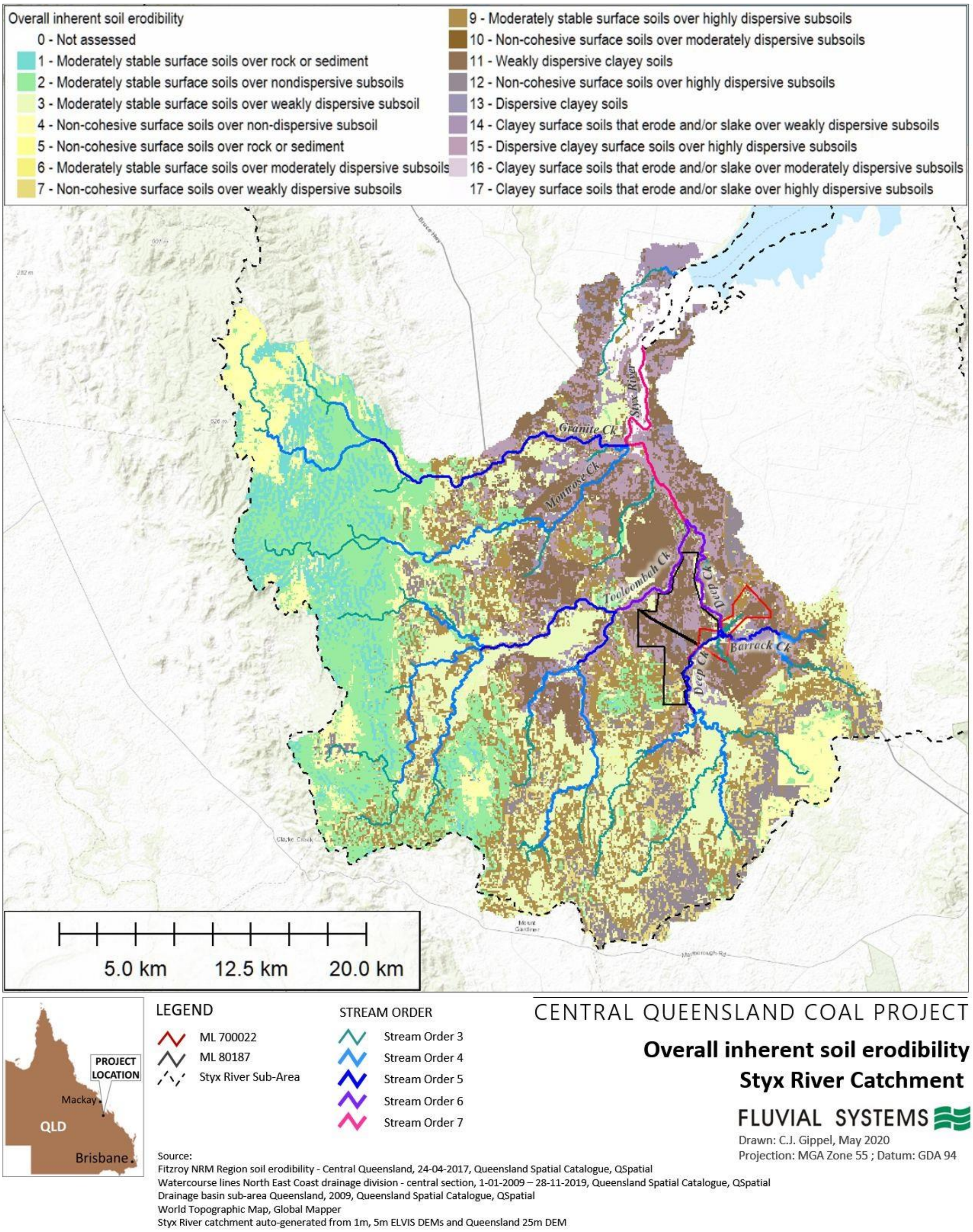
Source:
Fitzroy NRM Region surface soil erodibility - Central Queensland, 24-04-2017, Queensland Spatial Catalogue, QSpatial
Watercourse lines North East Coast drainage division - central section, 1-01-2009 – 28-11-2019, Queensland Spatial Catalogue, QSpatial
Drainage basin sub-area Queensland, 2009, Queensland Spatial Catalogue, QSpatial
World Topographic Map, Global Mapper
Styx River catchment auto-generated from 1m, 5m ELVIS DEMs and Queensland 25m DEM

Figure 15. Surface Soil Erodibility in Styx River catchment.



Source:
Fitzroy NRM Region surface soil erodibility - Central Queensland, 24-04-2017, Queensland Spatial Catalogue, QSpatial
Rendered on DEM derived from 1m, 5m ELVIS DEMs and Queensland 25m DEM

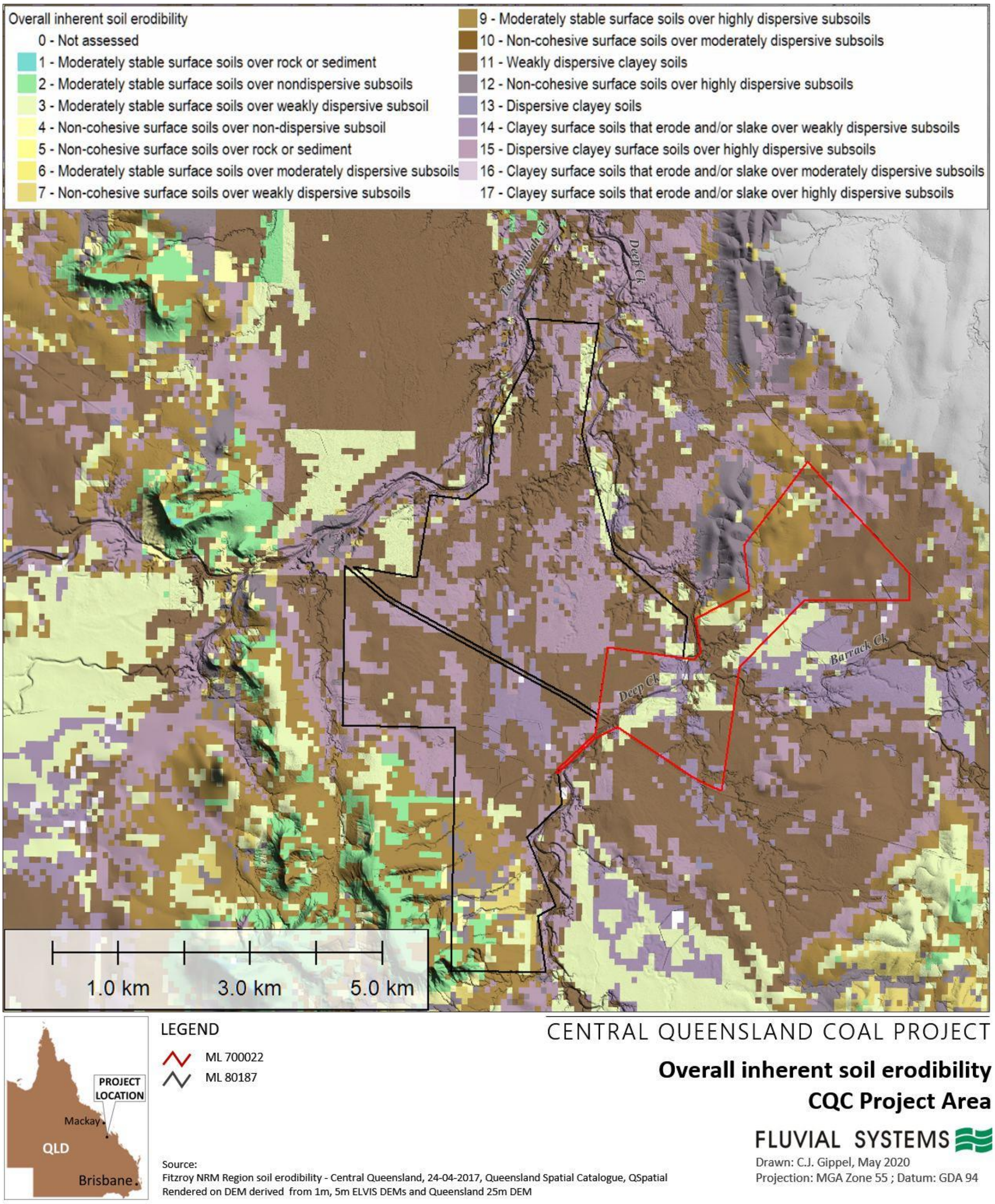
Figure 16. Surface Soil Erodibility in CQC Project area.



Drawn: C.J. Gippel, May 2020
Projection: MGA Zone 55 ; Datum: GDA 94

Source:
Fitzroy NRM Region soil erodibility - Central Queensland, 24-04-2017, Queensland Spatial Catalogue, QSpatial
Watercourse lines North East Coast drainage division - central section, 1-01-2009 – 28-11-2019, Queensland Spatial Catalogue, QSpatial
Drainage basin sub-area Queensland, 2009, Queensland Spatial Catalogue, QSpatial
World Topographic Map, Global Mapper
Styx River catchment auto-generated from 1m, 5m ELVIS DEMs and Queensland 25m DEM

Figure 17. Overall Inherent Soil Erodibility in Styx River catchment.



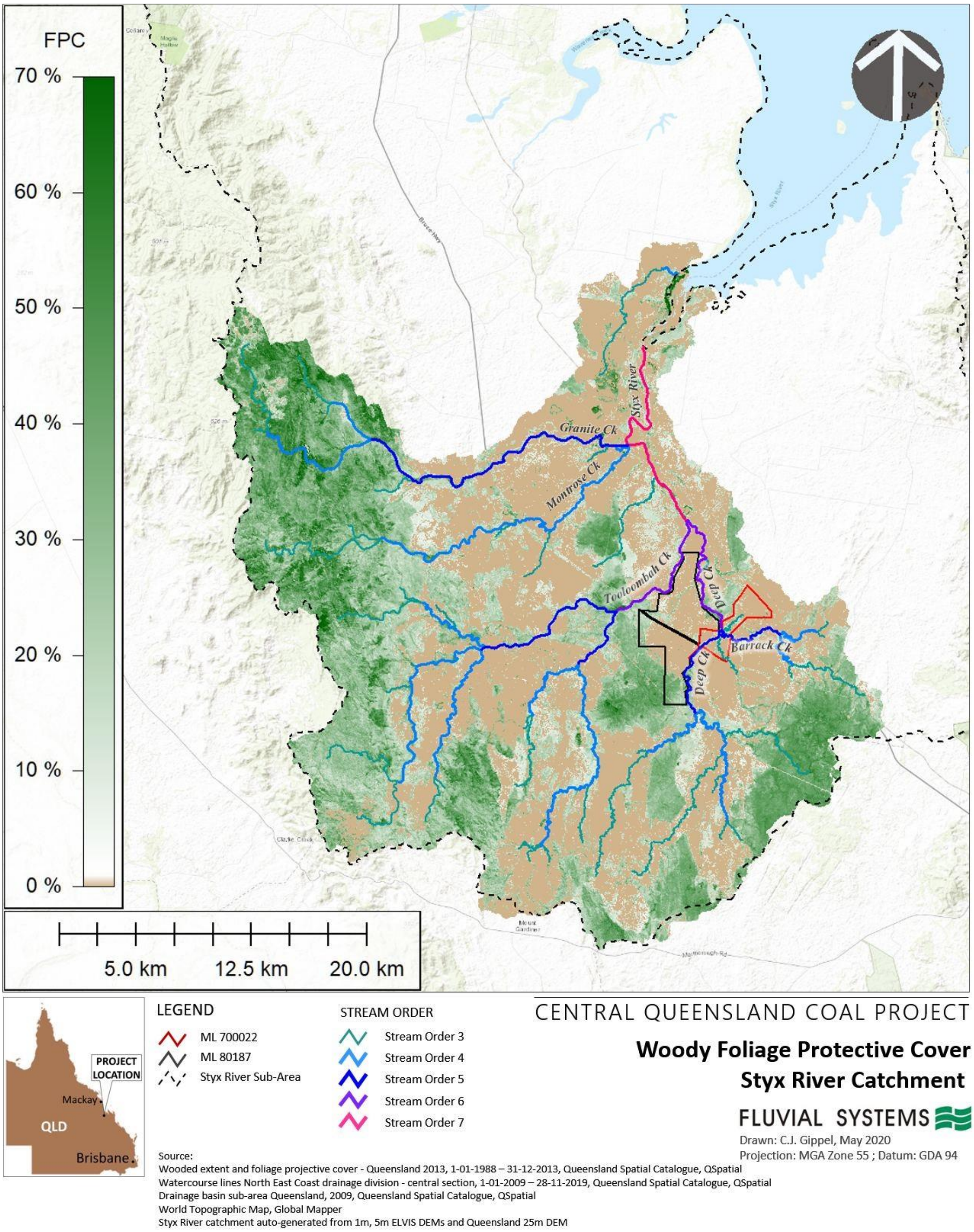
Source:
Fitzroy NRM Region soil erodibility - Central Queensland, 24-04-2017, Queensland Spatial Catalogue, QSpatial
Rendered on DEM derived from 1m, 5m ELVIS DEMs and Queensland 25m DEM

Drawn: C.J. Gippel, May 2020
Projection: MGA Zone 55 ; Datum: GDA 94

Figure 18. Overall Inherent Soil Erodibility in CQC Project area.

3.1.9 Woody foliage protective cover

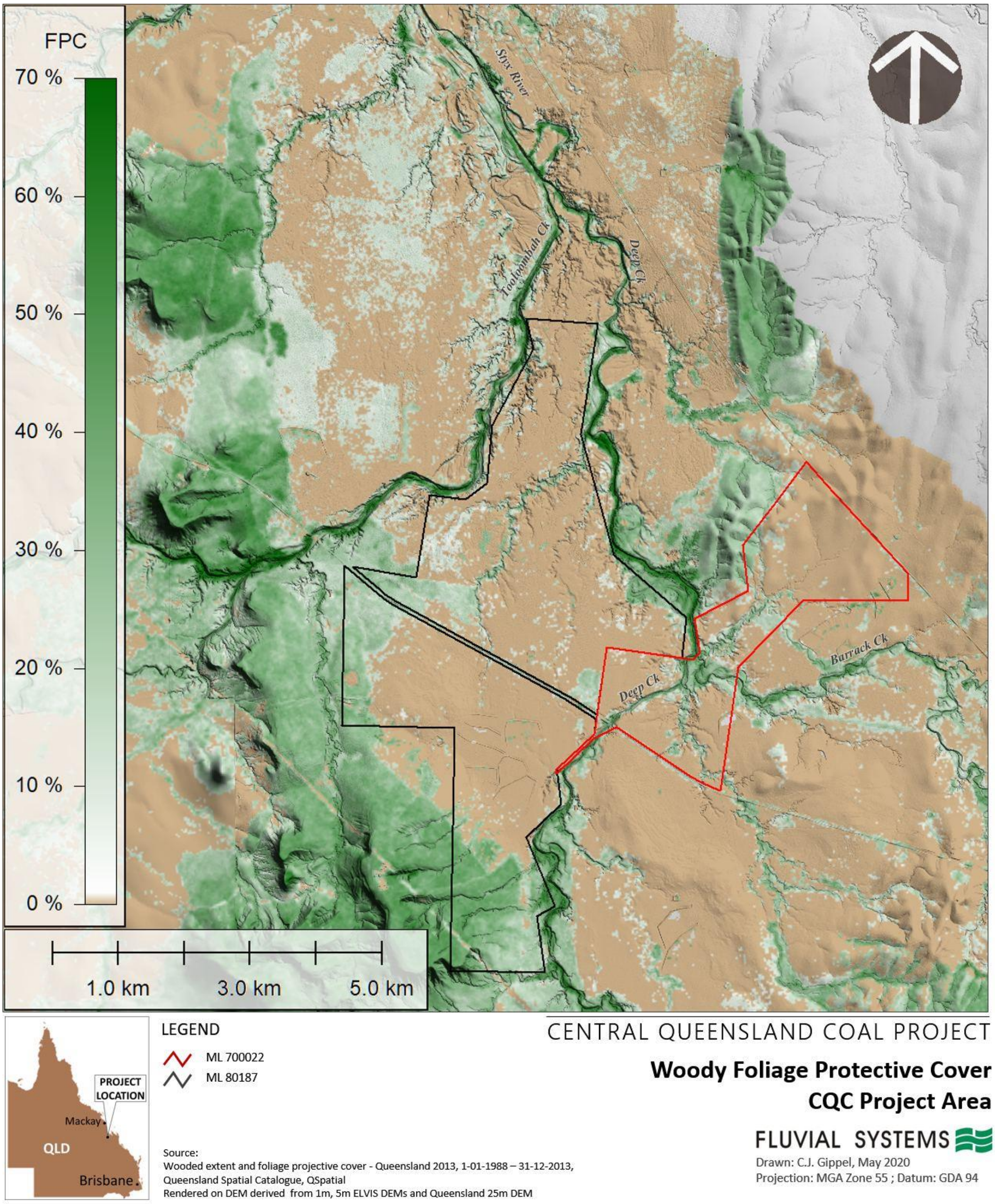
The distribution of woody vegetation over the Styx River catchment was strongly correlated with topography, with higher elevation headwater areas being forested, and lowland areas either lightly wooded or devoid of woody vegetation (Figure 19). Most of the CQC Project area had very low cover, or no cover, of woody vegetation (Figure 20). Moderate levels of woody vegetation cover were present within the incised channels of the major watercourses, but the vegetation did not extend to the surrounding Pleistocene terraces (Figure 20).



Drawn: C.J. Gippel, May 2020
Projection: MGA Zone 55 ; Datum: GDA 94

Source:
Wooded extent and foliage projective cover - Queensland 2013, 1-01-1988 – 31-12-2013, Queensland Spatial Catalogue, QSpatial
Watercourse lines North East Coast drainage division - central section, 1-01-2009 – 28-11-2019, Queensland Spatial Catalogue, QSpatial
Drainage basin sub-area Queensland, 2009, Queensland Spatial Catalogue, QSpatial
World Topographic Map, Global Mapper
Styx River catchment auto-generated from 1m, 5m ELVIS DEMs and Queensland 25m DEM

Figure 19. Woody foliage protective cover for the Styx River catchment.

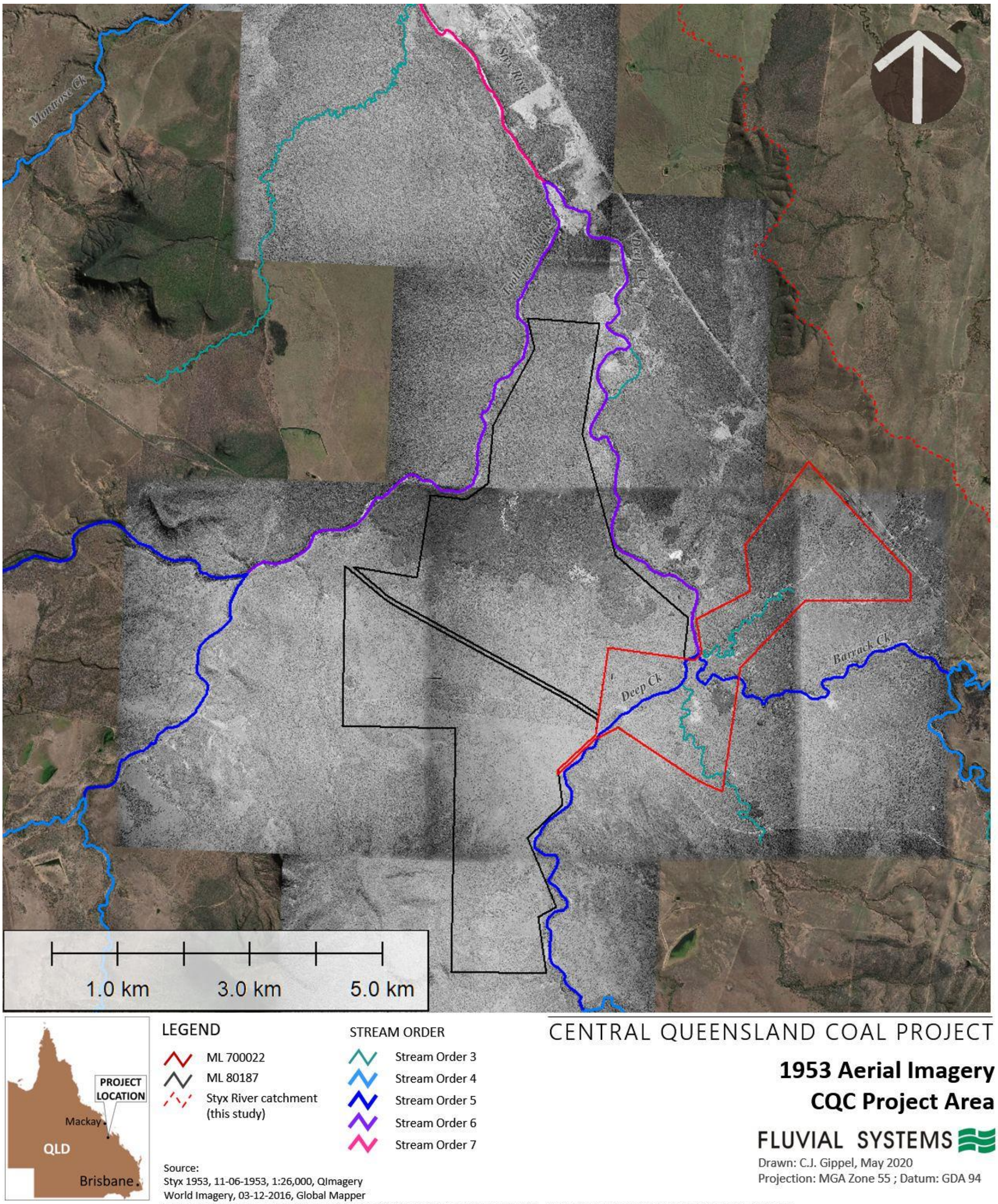


Source:
Wooded extent and foliage projective cover - Queensland 2013, 1-01-1988 – 31-12-2013, Queensland Spatial Catalogue, QSpatial
Rendered on DEM derived from 1m, 5m ELVIS DEMs and Queensland 25m DEM

Figure 20. Woody foliage protective cover for the CQC Project area.

3.1.10 1953 land cover

The CQC Project area was almost entirely forested in 1953 (Figure 21). Clearing had taken place in limited areas near Ogmore and along Kooltandra Road. Otherwise the lowland part of the Styx River valley was densely forested. A marked vegetation boundary existed in 1953 on land now within the CQC Project area. This vegetation boundary was used as the boundary between Somerby and Plainview Land Systems. The vegetation associated with Somerby is Eucalypt woodland (Table 3). In 1953, the riparian zones of watercourses within the Styx River catchment were densely vegetated.



Source:
Styx 1953, 11-06-1953, 1:26,000, QImagery
World Imagery, 03-12-2016, Global Mapper
Watercourse lines North East Coast drainage division - central section, 1-01-2009 – 28-11-2019, Queensland Spatial Catalogue, QSpatial

Figure 21. Land cover depicted on rectified and stitched 1953 aerial imagery over the CQC Project area.

3.1.11 NDRP Storm Tide Hazard Interpolation, highest astronomical tide and Styx River downstream limit

The theoretical maximum tide event extended 4.5 km upstream of the junction of Tooloombah and Deep Creeks. The 1000 year ARI event almost reached the junction Tooloombah and Deep Creeks (Figure 22).

The highest astronomical tide extended to the junction of Tooloombah and Deep Creeks (Figure 23).The Styx River downstream limit, corresponding to the point to which the high spring tide ordinarily flows and reflows, was marked 1.72 km downstream of the highest astronomical tide (Figure 23). The position of the normal high spring tide limit was drawn 106 m further upstream than the maximum upstream extent of the NDRP Storm Tide Hazard Interpolation 20, 50 and 100 year ARI events. The LiDAR data did not suggest the existence of a physical barrier in the river at that location. The apparent discrepancy could reflect the accuracy of the NDRP Storm Tide Hazard Interpolation mapping or inconsistent observations of the position of the normal spring tide limit depending on the presence of the tidal bore and sedimentation and scouring of bars near the tidal limit.

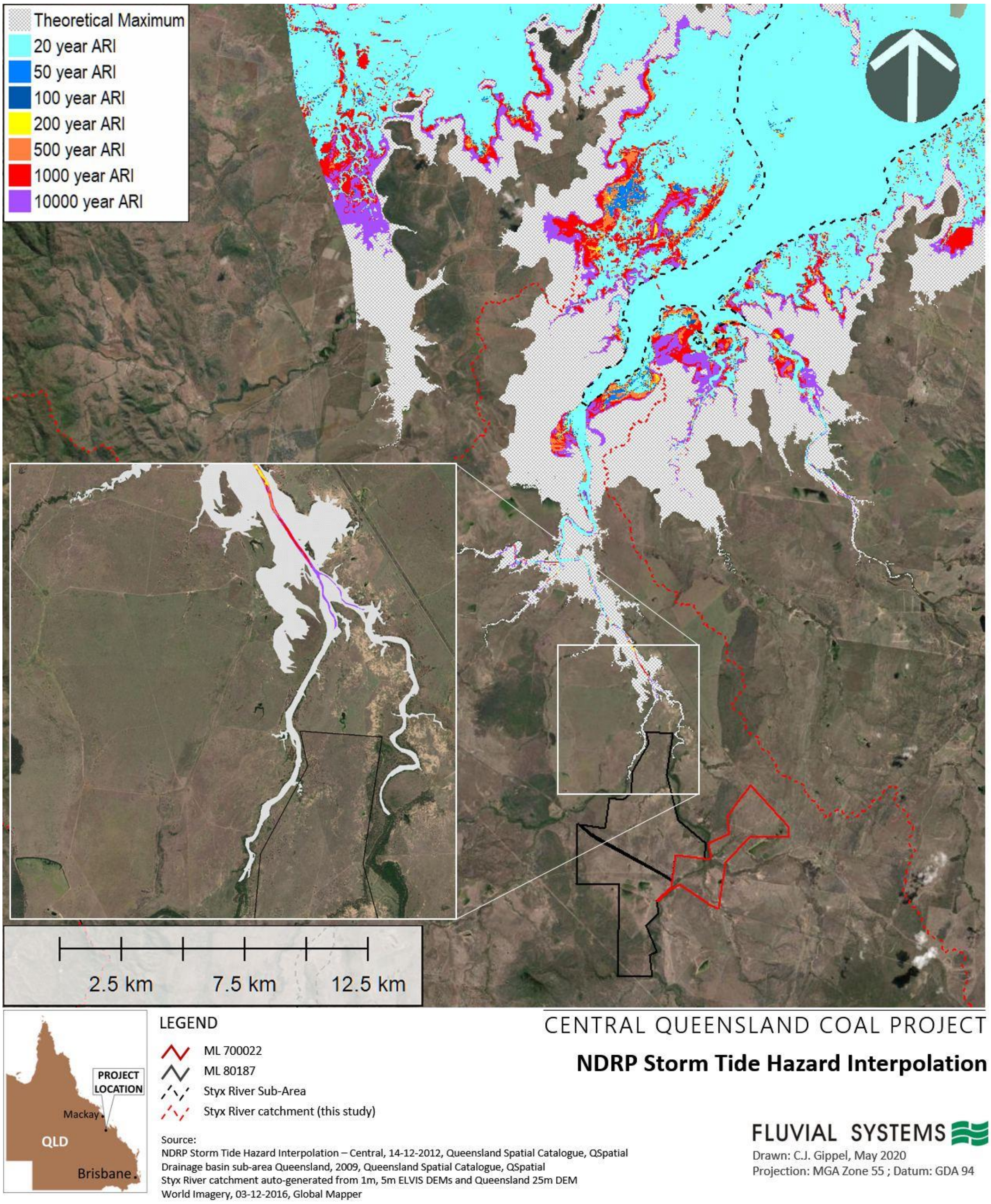
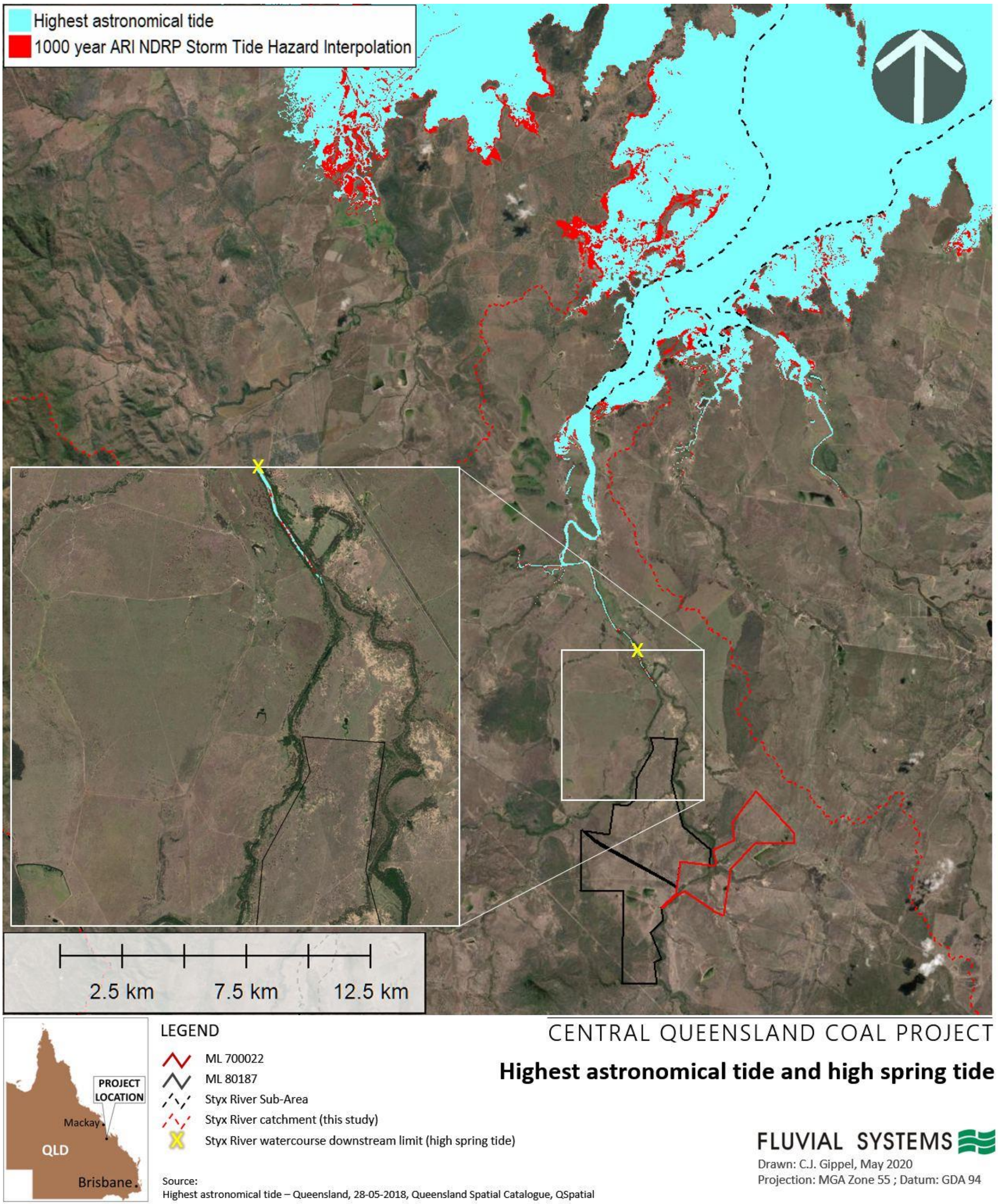


Figure 22. NDRP Storm Tide Hazard Interpolation for the CQC Project area.



Source:
Highest astronomical tide – Queensland, 28-05-2018, Queensland Spatial Catalogue, QSpatial
NDRP Storm Tide Hazard Interpolation – Central, 14-12-2012, Queensland Spatial Catalogue, QSpatial
Watercourse identification map - downstream limits – Queensland, 1/05/2020, Queensland Spatial Catalogue, QSpatial
Drainage basin sub-area Queensland, 2009, Queensland Spatial Catalogue, QSpatial
Styx River catchment auto-generated from 1m, 5m ELVIS DEMs and Queensland 25m DEM
World Imagery, 03-12-2016, Global Mapper

Figure 23. Highest astronomical tide and high spring tide limit for the CQC Project area.

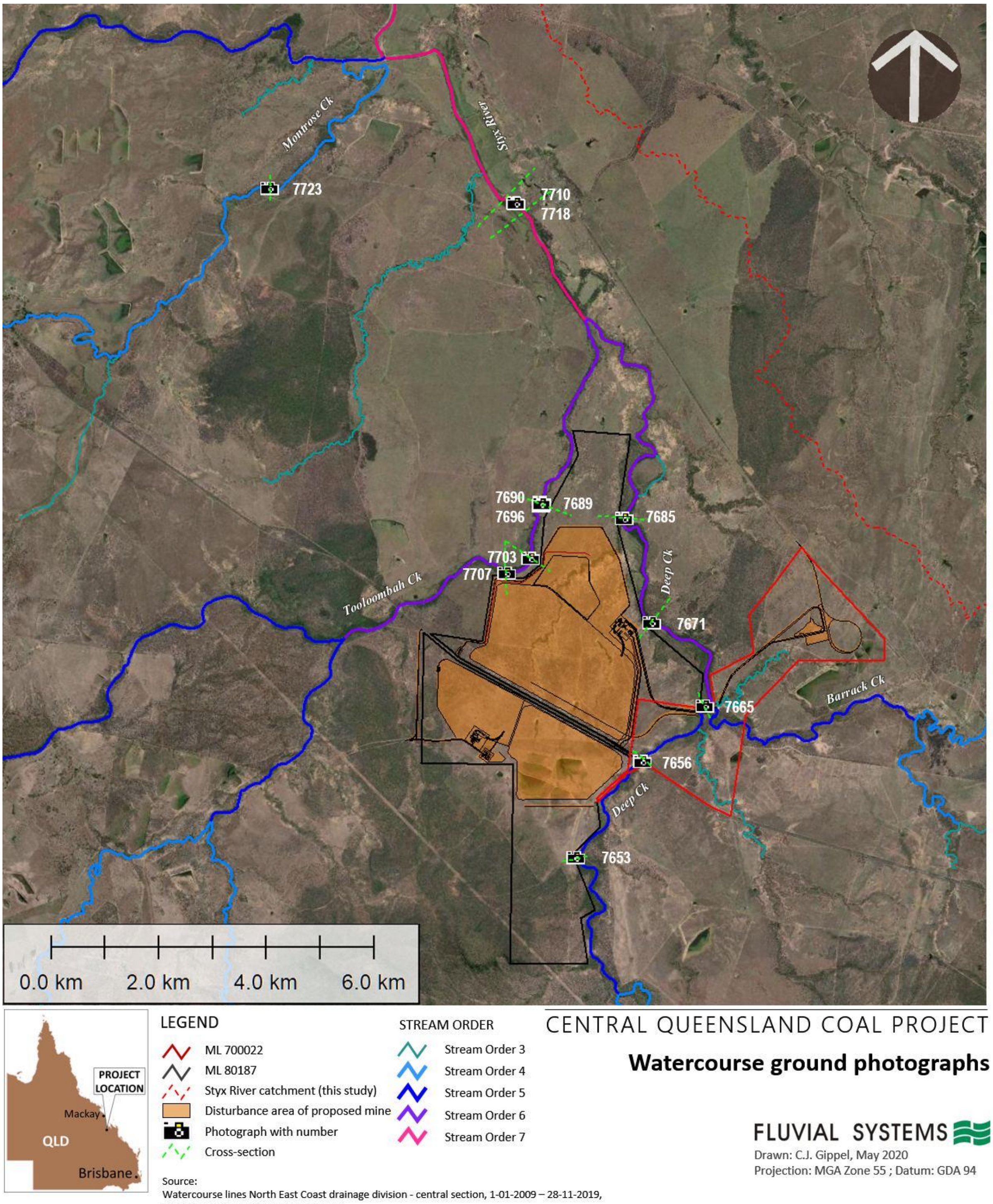
3.2 Reach- and Point-Scale Characteristics

3.2.1 Watercourse site geomorphic characteristics

The basic geomorphic character of the main watercourses in the CQC Project area (Table 23) was determined at a number of selected locations where ground photographs were taken (Figure 24). Geomorphic character was determined from aerial photography, ground photographs (Figure 25, Figure 26 and Figure 27), cross-sections drawn from LiDAR data at the locations of the ground photographs (Figure 28, Figure 29 and Figure 30), and long profiles along the main watercourses (Figure 31) drawn from the LiDAR data (Figure 32 and Figure 33).

Table 23. Geomorphic character of the main watercourses in the CQC Project area at selected locations. NA is not available.

Creek	Location (photo #)	Bed material (dominant listed first)	Mean stream link slope (m/m)	Sinuosity	Dimensions (active 10 yr ARI channel)	Morphology
Deep Creek	7653	Sand	0.0768	1.26 (low)	W: 80 m D: 7.0 m	Incised with inset bench
Deep Creek	7656	Sand / Mud	0.0656	1.07 (low)	W: 60 m D: 3.8 m	Incised with inset bench
Deep Creek	7665	Mud	0.0855	1.04 (low)	W: 70 m D: 6.5 m	Incised with inset bench
Deep Creek	7671	Mud	0.0620	1.08 (low)	W: 90 m D: 8.0 m	Incised with inset bench
Deep Creek	7685, at junction of creek in ML80187	Sand / Mud	0.0726 (upstream) 0.1013 (downstream)	1.26 (low)	W: 80 m D: 9.1 m	Incised with inset bench
Barrack Creek	Within ML700022	NA	0.0597	1.70 (meandering)	W: 20 m D: 3 m	Incised with inset bench
Tooloombah Creek	7707	Gravel / Cobble / Sand	0.0650	1.12 (low)	W: 100 m D: 9.2 m	Incised with wide inset floodplain
Tooloombah Creek	7703	Cobble / Gravel / Sand	0.0600	1.12 (low)	W: 150 m D: 8.9 m	Incised with wide inset floodplain
Tooloombah Creek	7690	Cobble / Gravel / Sand / Bedrock outcrop	0.0591	1.12 (low)	W: 100 m D: 9.9 m	Incised with narrow inset floodplain
Styx River	7718 and 7710	Fine sand	0.0354	1.06 (low)	W: 480 – 570 m D: 9.0 – 10.0 m	Incised with wide inset floodplain



Source:
Watercourse lines North East Coast drainage division - central section, 1-01-2009 – 28-11-2019, Queensland Spatial Catalogue, QSpatial
World Imagery, 03-12-2016, Global Mapper
Photographs supplied by David Newton, WRM, taken 17-10-2019

Figure 24. Locations of watercourse ground photographs, and associated cross-sections.

Figure 25. Deep Creek ground photographs.

Figure 26. Tooloombah Creek ground photographs.

Figure 27. Styx River and Montrose Creek ground photographs.

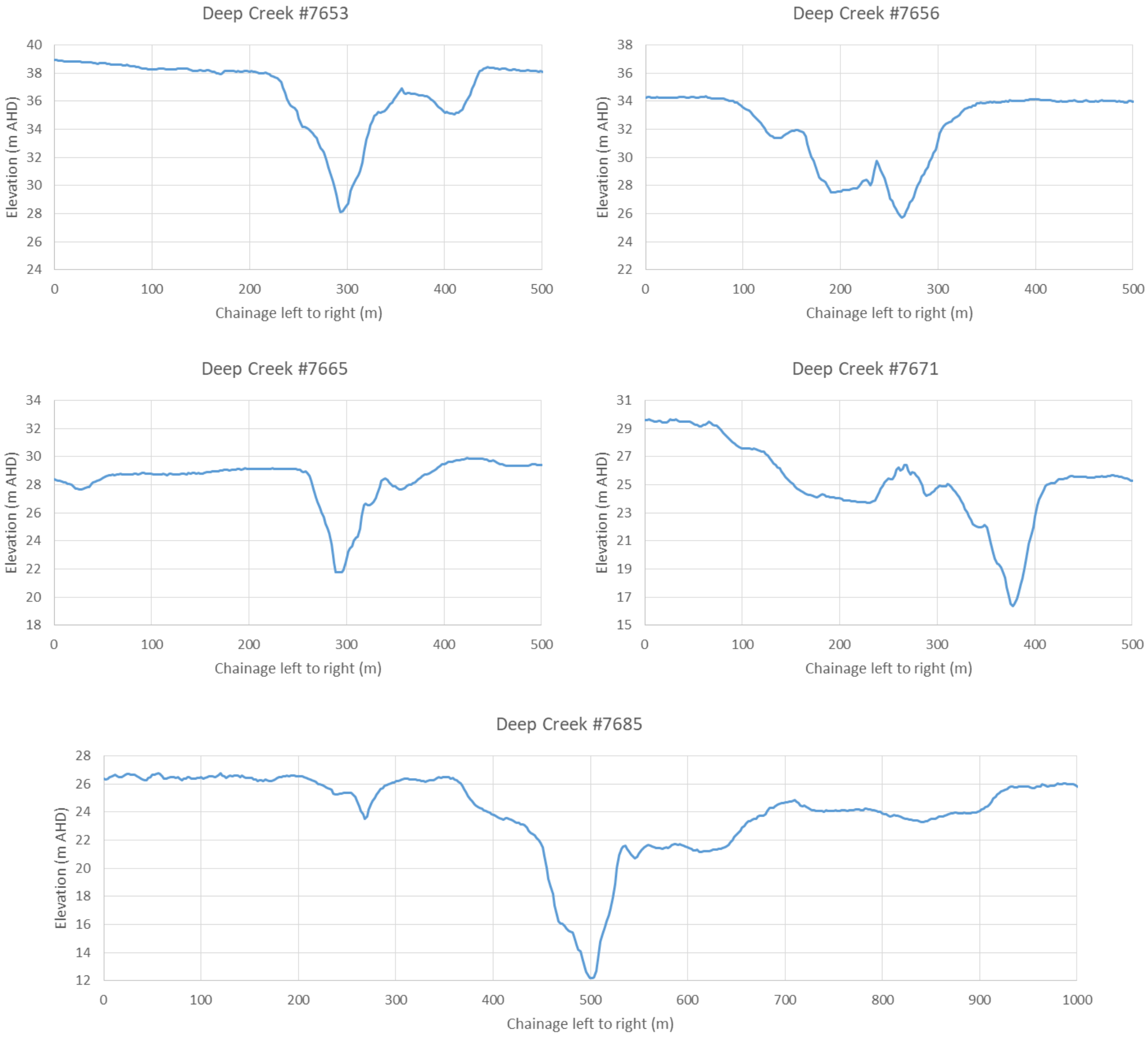


Figure 28. Deep Creek cross-sections.

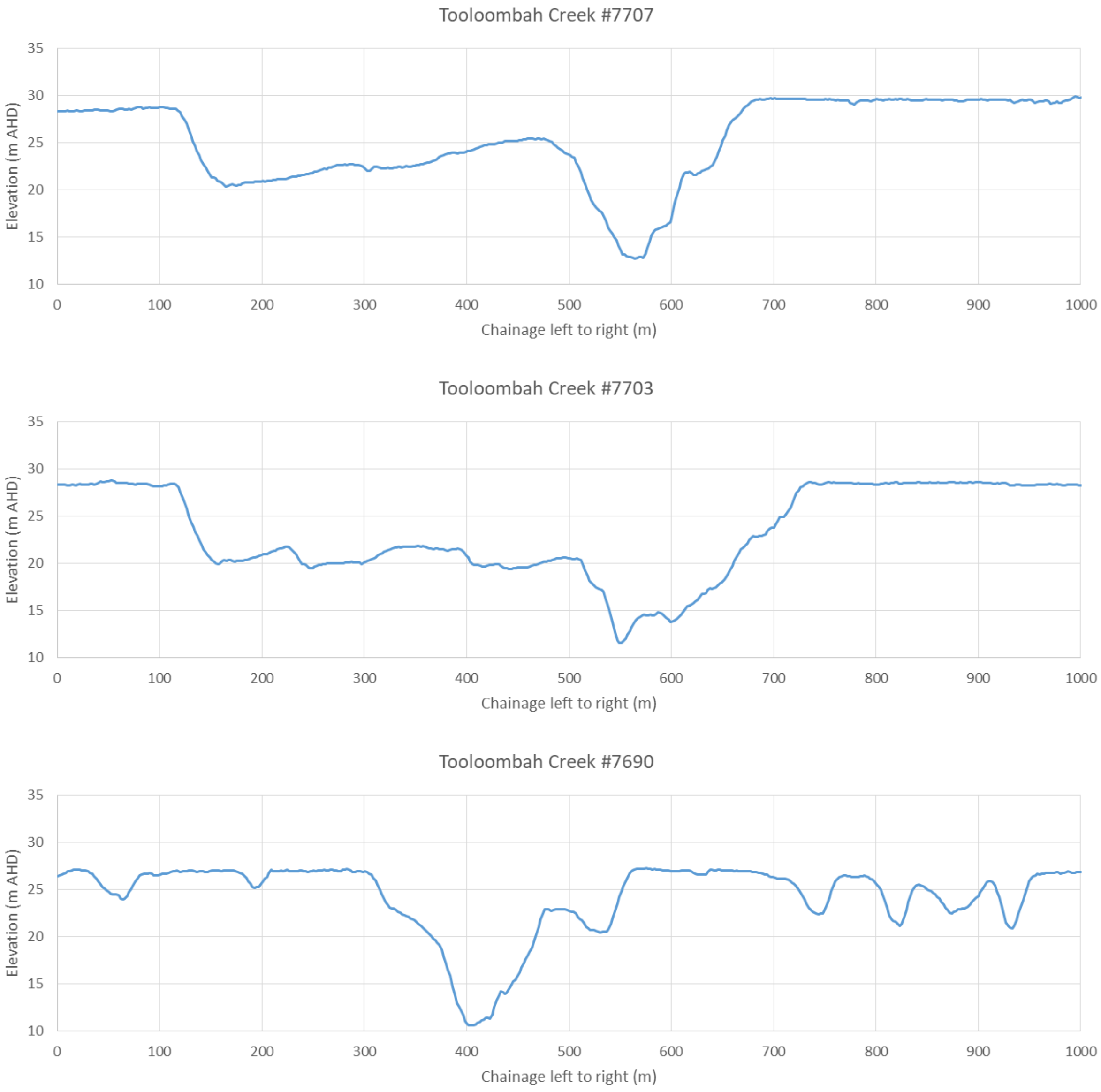


Figure 29. Tooloombah Creek cross-sections.

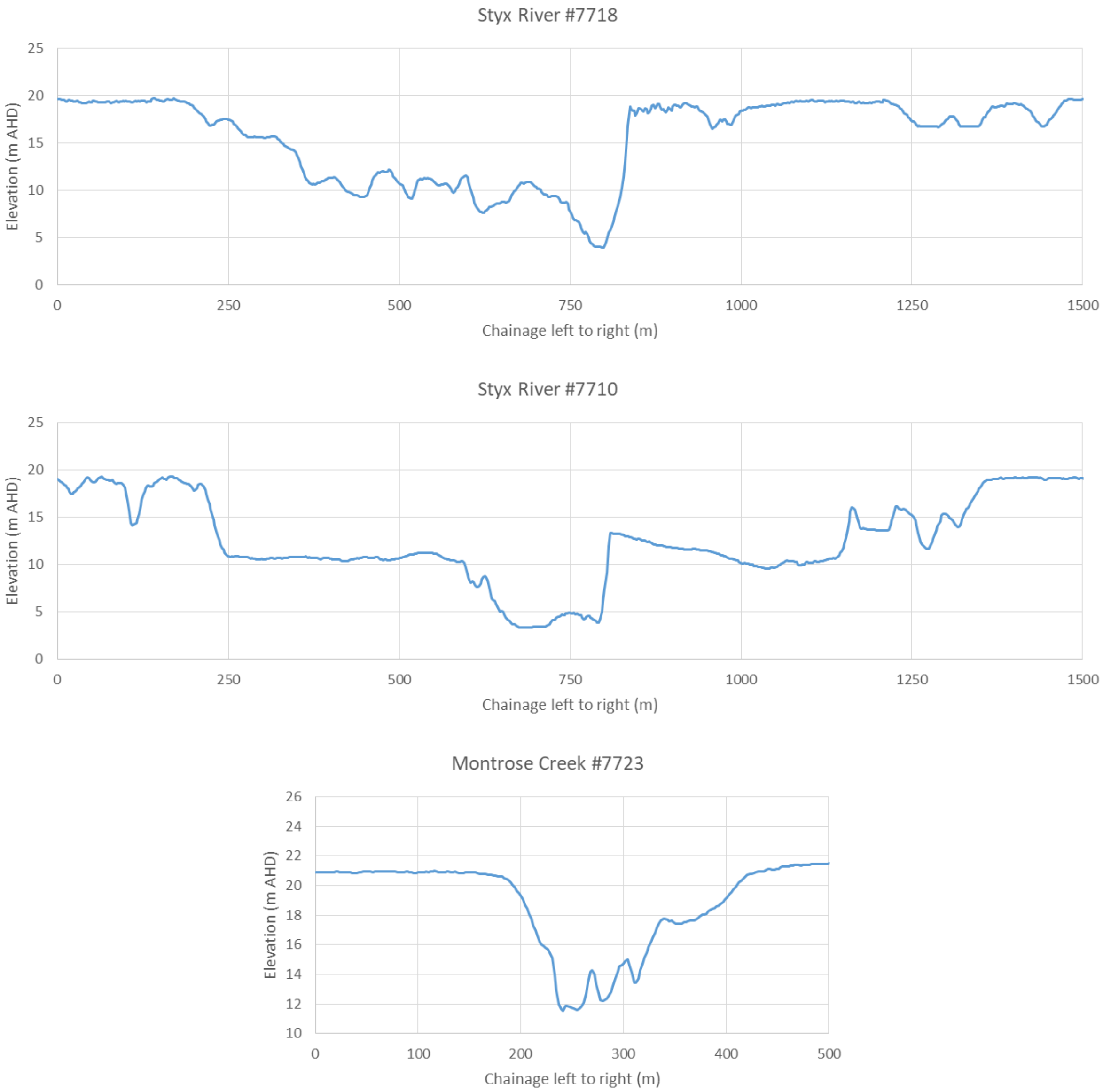
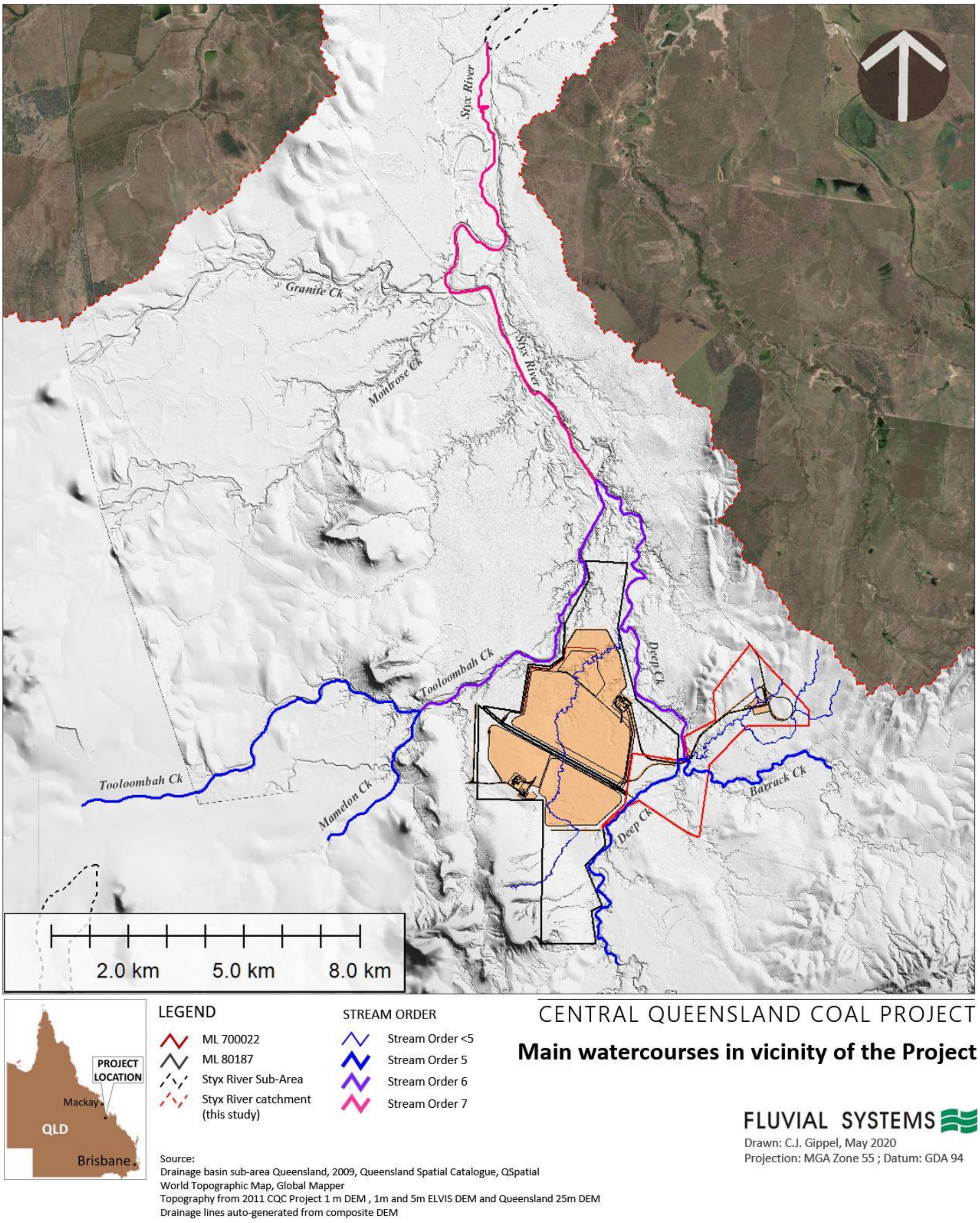


Figure 30. Styx River and Montrose Creek cross-sections.



Source:
Drainage basin sub-area Queensland, 2009, Queensland Spatial Catalogue, QSpatial
World Topographic Map, Global Mapper
Topography from 2011 CQC Project 1 m DEM , 1m and 5m ELVIS DEM and Queensland 25m DEM
Drainage lines auto-generated from composite DEM

Figure 31. Main watercourses in the vicinity of the CQC Project area.

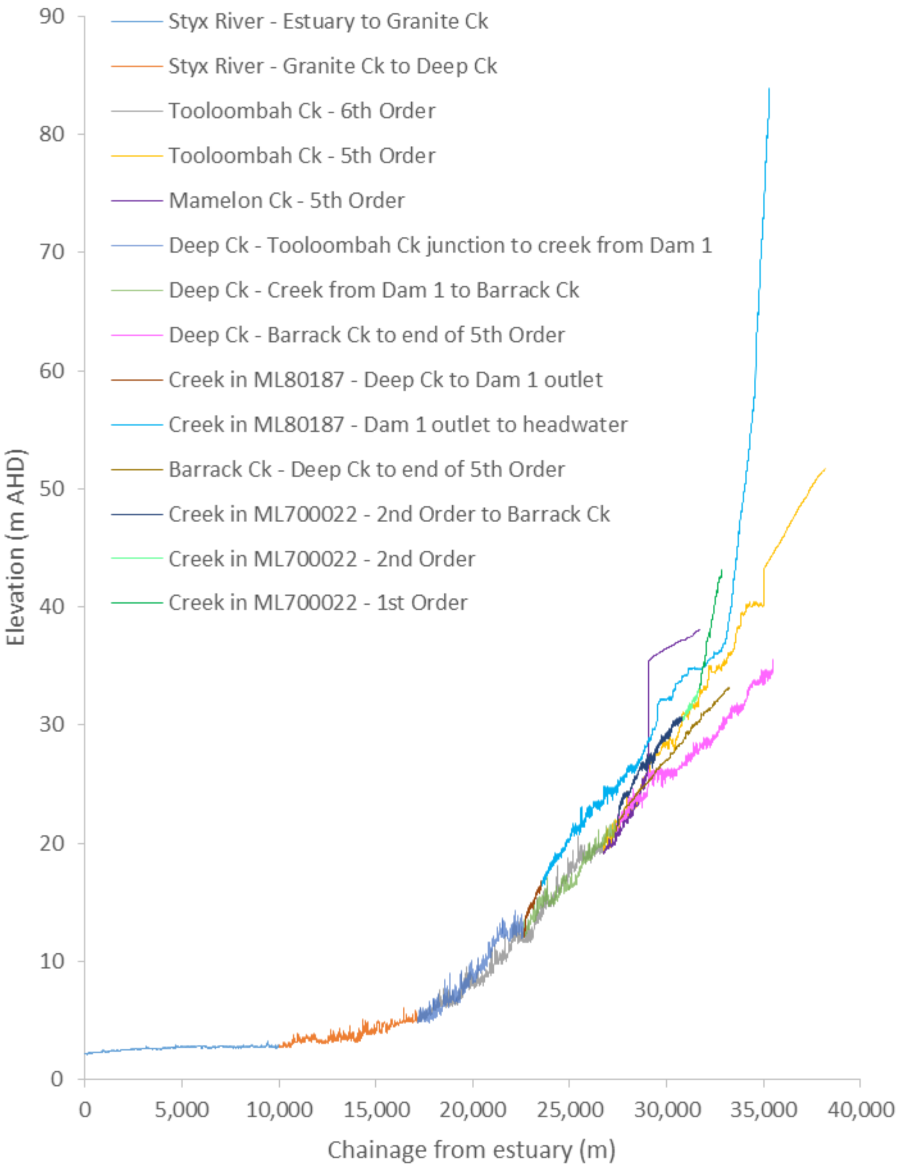


Figure 32. Long profiles of all main watercourses in the vicinity of the CQC Project area. Note: Discontinuity in Mamelon Creek and Toolombah Creek 5th Order corresponds with boundaries of LiDAR.

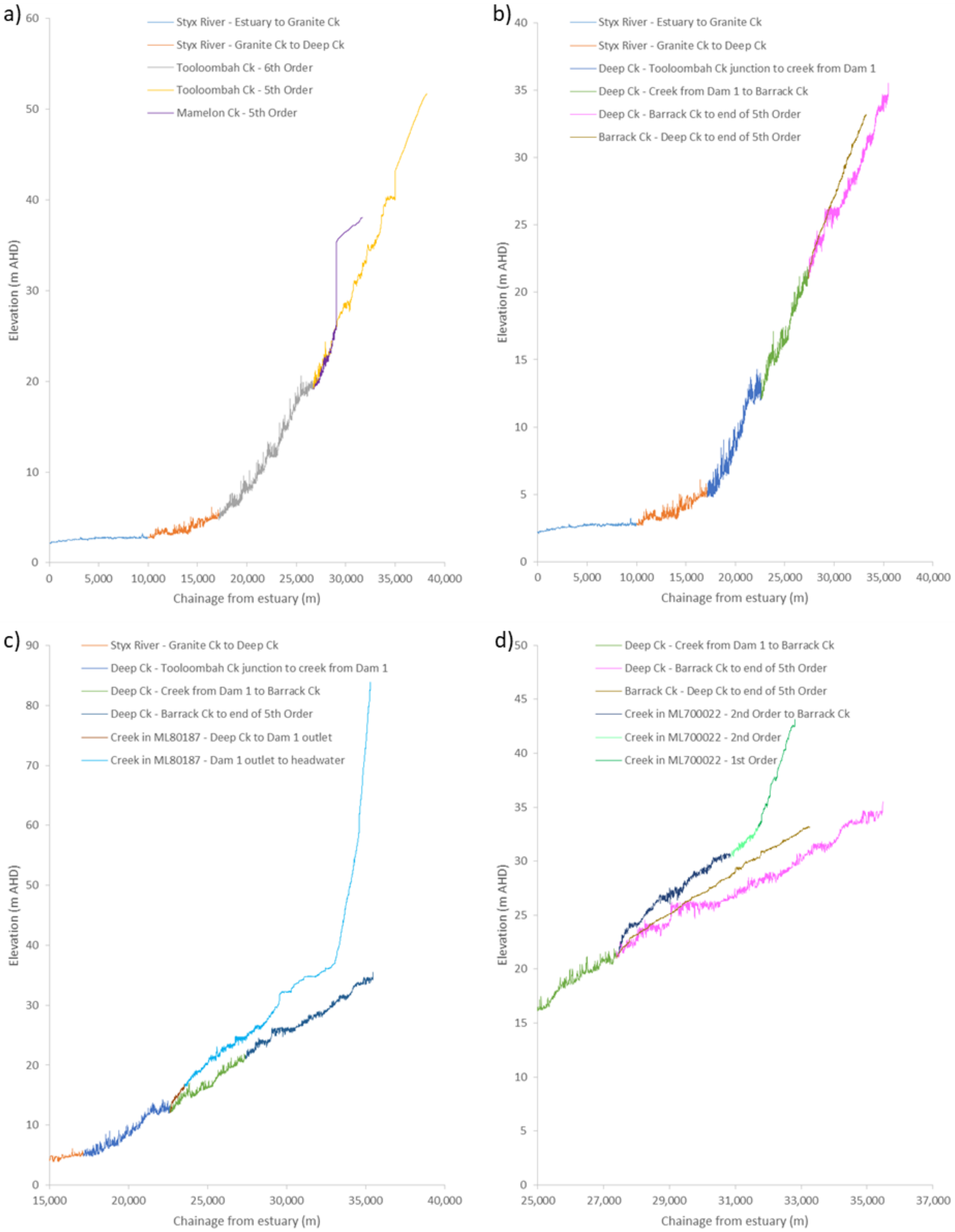


Figure 33. Long profiles of: a) Styx River/Tooloombah Creek watercourses, b) Styx River/Deep Creek/Barrack Creek watercourses, c) Deep Creek/creek in ML 80187 watercourses and d) Barrack Creek/creek in ML 700022 watercourses. Note: 1. Discontinuity in Mamelon Creek and Toolombah Creek 5th Order corresponds with boundaries of LiDAR; 2. Variable vertical exaggeration.

The active channels of the main watercourses in the CQC Project area were deeply incised into a broad plain of older alluvium. The active channel comprised depositional benches and inset floodplains formed through the Holocene from a mix of material sourced from the catchments in recent times plus reworked older Pleistocene material. The main channels were thus considered partly confined by the older alluvium unit. The threshold sinuosity to separate low sinuosity and meandering in River Styles® classification is 1.3 (Brierley and Fryirs, 2002). By this definition, sinuosity was low, except for Barrack Creek, which most likely had fine-grained bed material. The bed material determined from ground photographs ranged from fine-grained mud (silt and clay) to coarse cobble size. The thresholds of landform slope classes used by Speight (2009) were level <0.01, very gentle 0.01 – 0.03, gently inclined 0.03 – 0.10, moderately inclined 0.10 – 0.32, steep 0.32 – 0.56, very steep 0.56 – 1.00, precipitous >1. In contrast, River Styles® assessments typically classify stream bed slopes >~0.01 m/m as ‘steep’, slopes ~0.003 – ~0.01 low to moderate slope and <~0.003 low slope. By the classification of Speight (2009), all of the main streams in the CQC Project area were in the gently inclined landform class, but by River Styles® convention they would all be considered steep. The difference is related to Speight’s (2009) classification covering all landforms, while River Styles® is river-specific and did not follow the existing convention. Also, River Styles® surveys are typically limited to Third Order streams and larger, ignoring the steep headwater streams. Thus, relative to large lowland rivers, the streams in the Styx valley could be considered steep, but relative to the full spectrum of drainage lines found in a typical east coast catchment, they are not particularly steep.

3.2.2 Stream geomorphic type, condition and fragility

Stream geomorphic type (equivalent to River Styles®) was determined for the main watercourses in the CQC Project area using the information collected for this report (Table 24). Fragility is based on the adjustment potential of streams under the three categories: channel attributes (geometry, size and connection to floodplain), planform (lateral stability, number of channels and sinuosity) and bed character (bedform and bed materials). The fragility ratings for each river type were taken from River Styles® literature. Condition was rated Moderate for all stream reaches on the basis that the incised nature of the channels was natural (i.e. this was not a characteristic that would automatically result in a low condition in this area), riparian vegetation was impaired in terms of width and continuity but present in most places, and gullies were contributing suspended sediment to the streams at a rate higher than what would be expected in an unimpaired catchment. (Cook and Schneider, 2006).

Stream types with “Low fragility” are resilient or “unbreakable”, those with “Medium fragility” have local adjustment potential, and those with “High fragility” have significant adjustment potential. Streams reaches with high fragility and poor condition are rated low priority, while reaches with low fragility that are in good geomorphic condition are rated the highest priority for protection. On this basis, the high fragility Tooloombah Creek, Deep Creek and Styx River (non-tidal) would be lower priority for rehabilitation than Barrack Creek and Styx River (upper-tidal). However, there are other reasons that might influence the prioritisation of rivers for rehabilitation. In the Styx valley, where reduction of sediment load to the Great Barrier Reef is an established objective (Department of Agriculture, Water and the Environment, 2018), the main criterion for prioritisation would be the potential to generate suspended sediment. This would shift the focus to alluvial gullies (not generally assessed in River Styles®), and particular river bends with a recognised rapid migration rate.

Table 24. Geomorphic type of the main watercourses in the CQC Project area.

Watercourse	Valley Setting	Channel	Sinuosity	Dominant particle size	Geomorphic Type	Geomorphic condition	Fragility
Deep Creek	Partly confined	Continuous/ single	Low	Sand / fine	Planform Controlled, Low Sinuosity Sand/Fine	Moderate	High
Tooloombah Creek	Partly confined	Continuous/ single	Low	Cobble	Planform Controlled Low Sinuosity Cobble	Moderate	High
Barrack Creek	Partly confined	Continuous/ single	Meandering	Fine	Planform Controlled Meandering Fine Grained	Moderate	Medium
Styx River (non-tidal)	Partly confined	Continuous/ single	Low	Sand	Planform Controlled, Low Sinuosity Sand	Moderate	High
Styx River (upper tidal)	Partly confined	Continuous/ single	Low	Sand	Planform Controlled Tidal	Moderate	Low

3.2.3 Distribution of velocity and bed shear stress (BSS) under the 10% and 1% AEP flood events

Under both the 10% AEP and 1% AEP event conditions the velocity on the floodplain areas was mostly less than 1 m/s (Figure 34 and Figure 35 respectively). Grassed floodplains would have low risk of scour under these conditions, although there would be moderate risk for exposed soil surfaces (Table 18). Under the 10% AEP event conditions, the channel velocities were mostly less than 2 m/s (Figure 34), while under the 1% AEP event conditions, the channel velocities exceeded 2 m/s in some areas, but were mostly less than 3 m/s (Figure 35). These velocities would be associated with expected sediment transport processes, and expected scour of banks in some exposed locations on the outside of meander bends. Well vegetated banks would have lower risk of bank erosion (Table 18).

Under both the 10% AEP and 1% AEP event conditions the BSS values on the floodplain areas was mostly less than 25 N/m^2 (Figure 36 and Figure 37 respectively). Grassed floodplains would have low risk of scour under these conditions, although there would be moderate risk for exposed soil surfaces (Table 18). Under the 10% AEP event conditions, the channel BSS values were mostly less than 100 N/m^2, with some short sections up to 200 N/m^2 (Figure 36). Under the 1% AEP event conditions, the channel BSS values exceeded 100 N/m^2 over longer reaches, and some short sections exceeded 200 N/m^2 (Figure 37). These values of BSS would be associated with expected sediment transport processes, with sand, gravel and cobble sized material subject to mobilisation. Also, this distribution of BSS would be associated with expected scour of banks in some exposed locations on the outside of meander bends. Well vegetated banks would have lower risk of bank erosion (Table 18).

The modelled velocity and bed shear stress values suggest that the watercourses in the CQC Project area are geomorphologically active, with bed sediment transport and channel migration process to be expected. The grassed floodplain surfaces would be depositional rather than erosional zones. Well-vegetated banks would have significantly lower risk of erosion than banks formed by exposed soils.

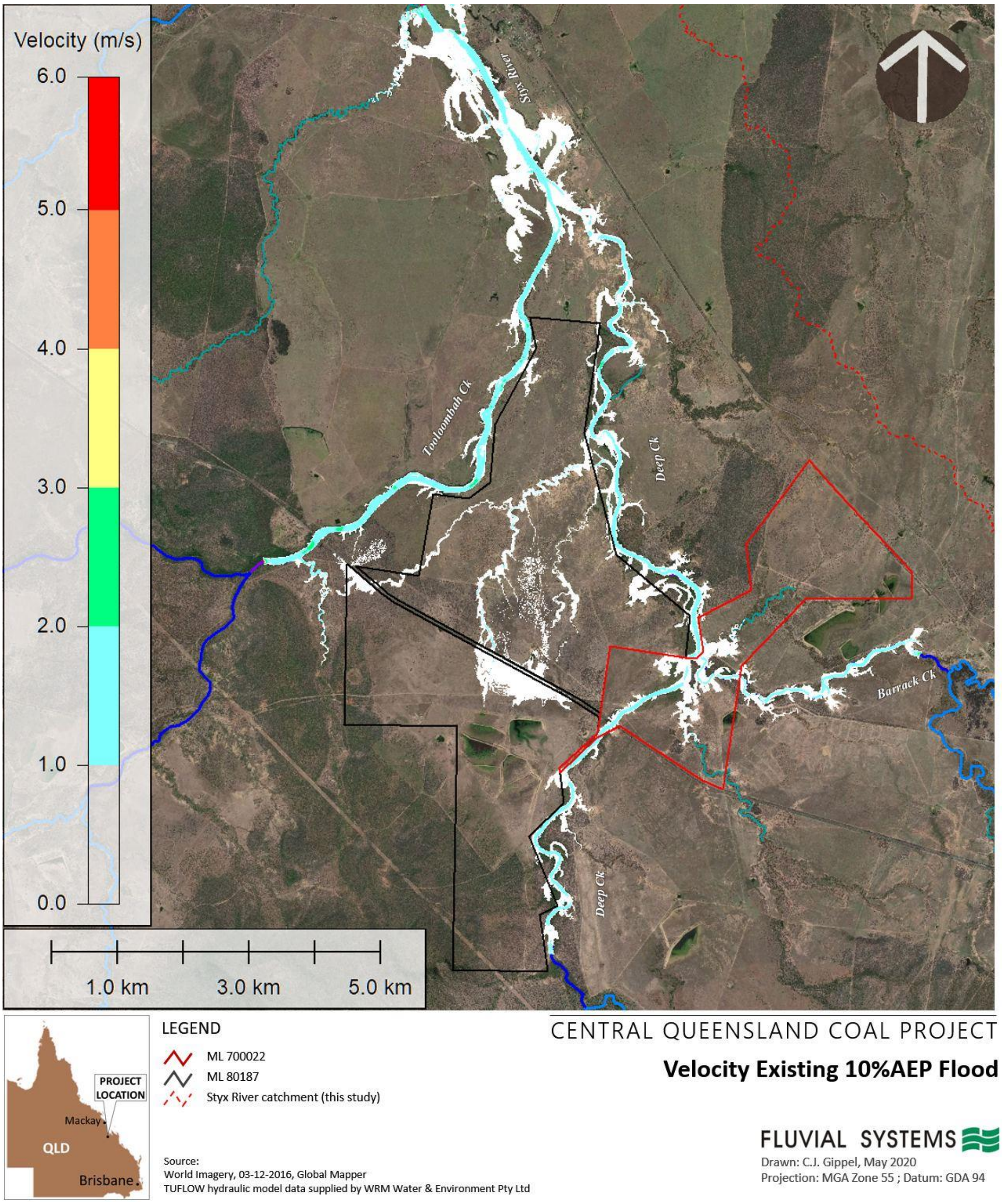
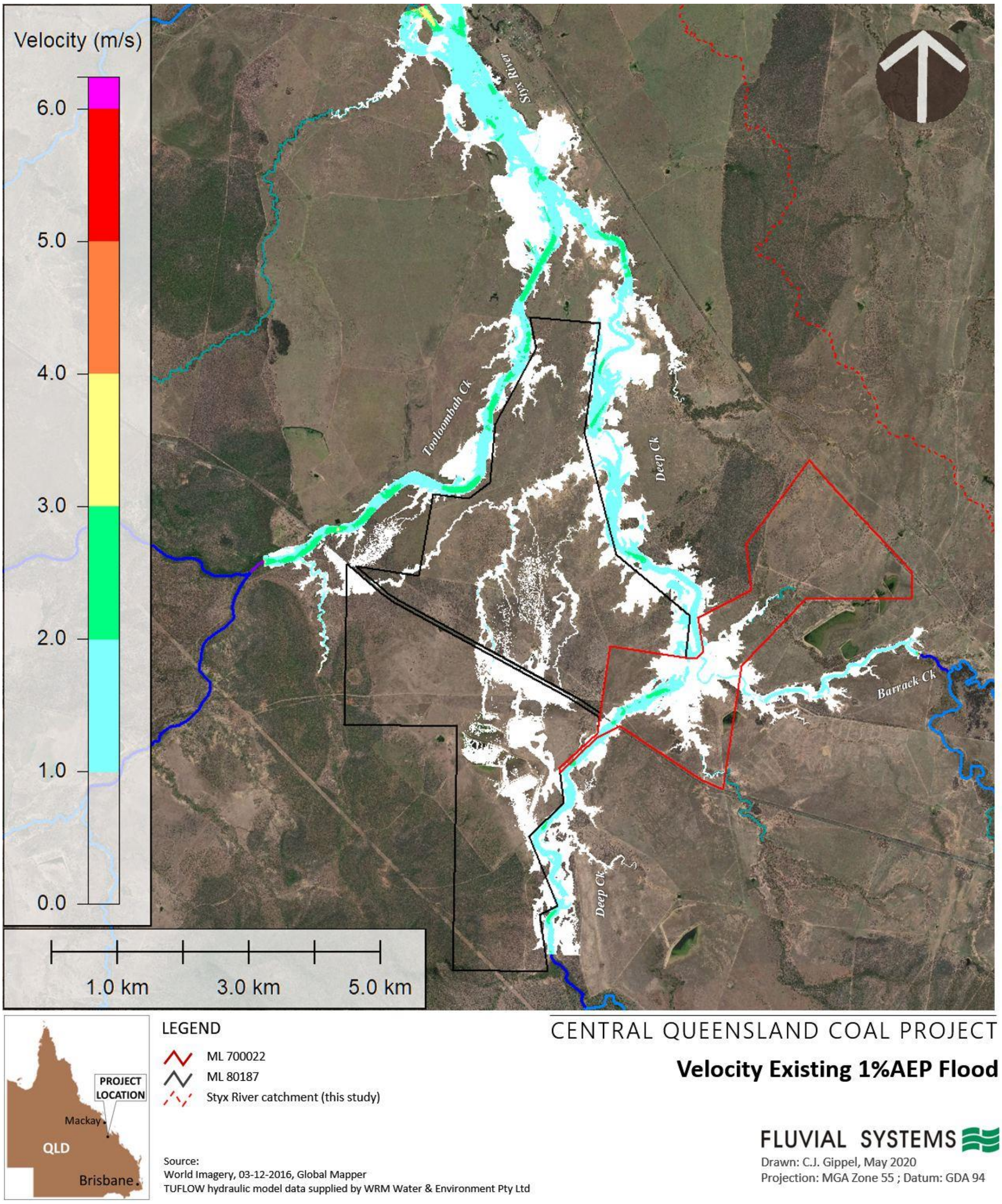


Figure 34. Distribution of velocity classes, modelled for the 10% AEP flood event under the existing scenario. A small number of cells with values exceeding 4 m/s can be considered outliers.



Source:
World Imagery, 03-12-2016, Global Mapper
TUFLOW hydraulic model data supplied by WRM Water & Environment Pty Ltd

Figure 35. Distribution of velocity classes, modelled for the 1% AEP flood event under the existing scenario. A small number of cells with values exceeding 4 m/s can be considered outliers.

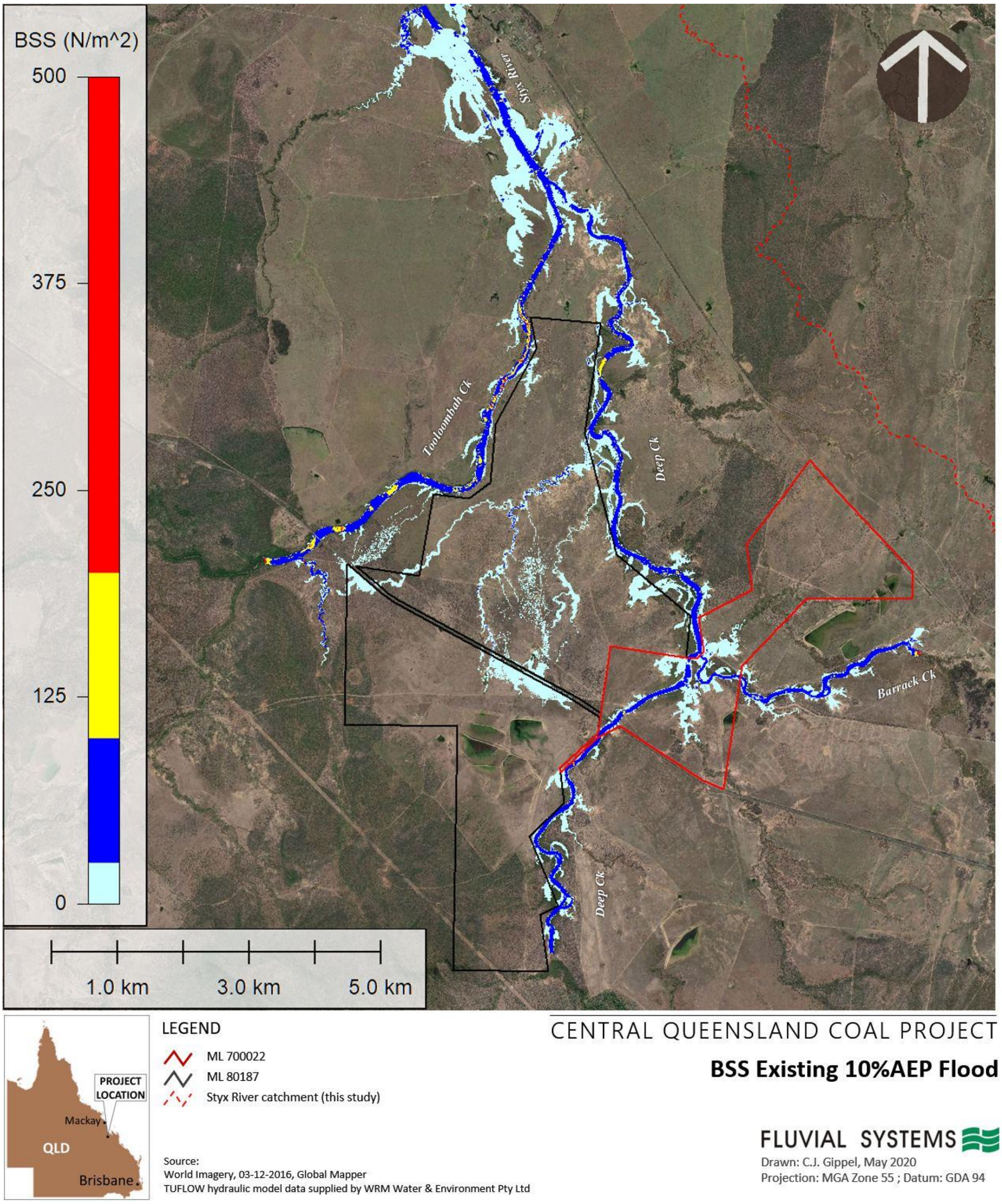
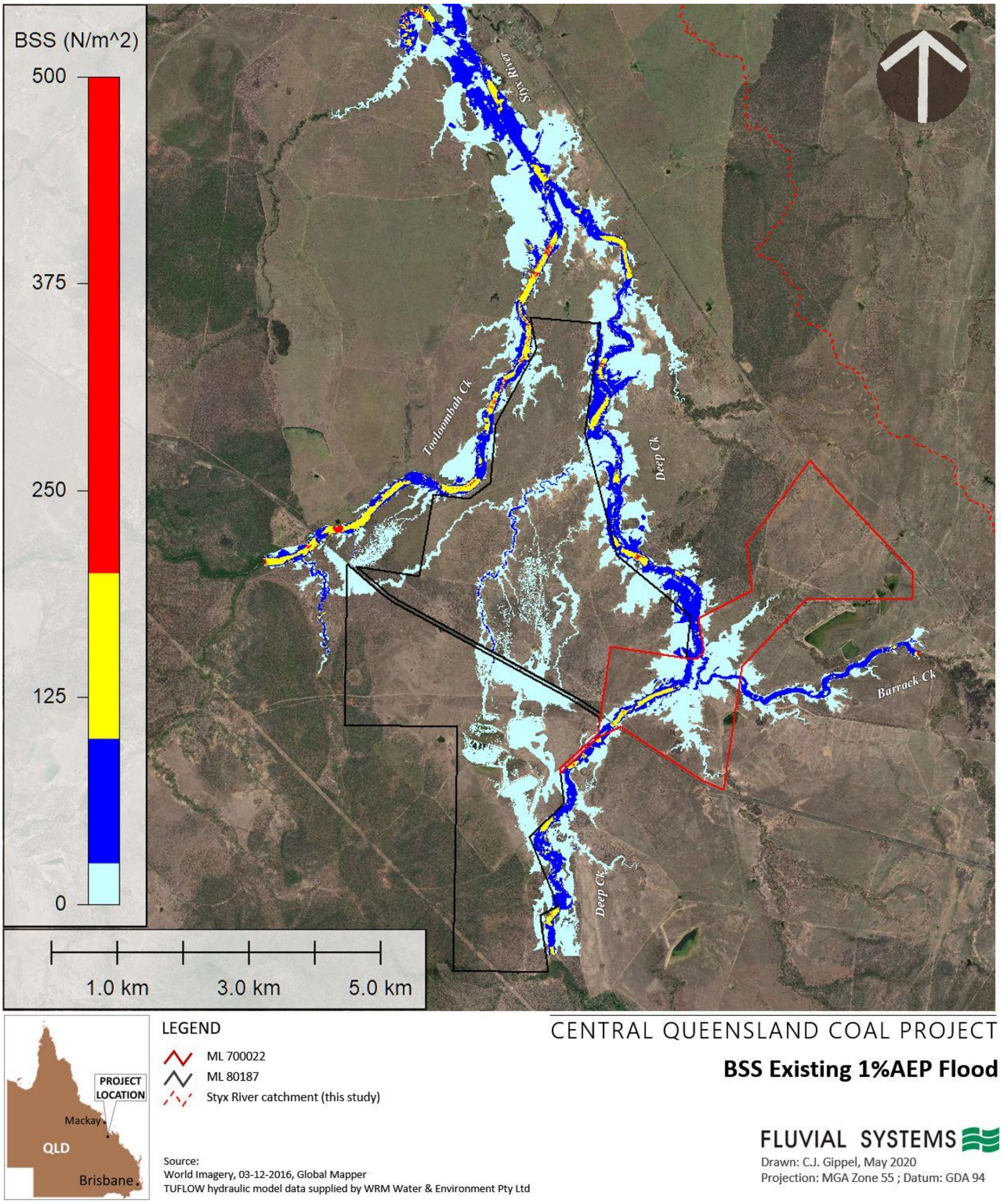


Figure 36. Distribution of bed shear stress (BSS) classes, modelled for the 10% AEP flood event under the existing scenario. A small number of cells with values exceeding 500 N/m^2 were excluded as outliers.



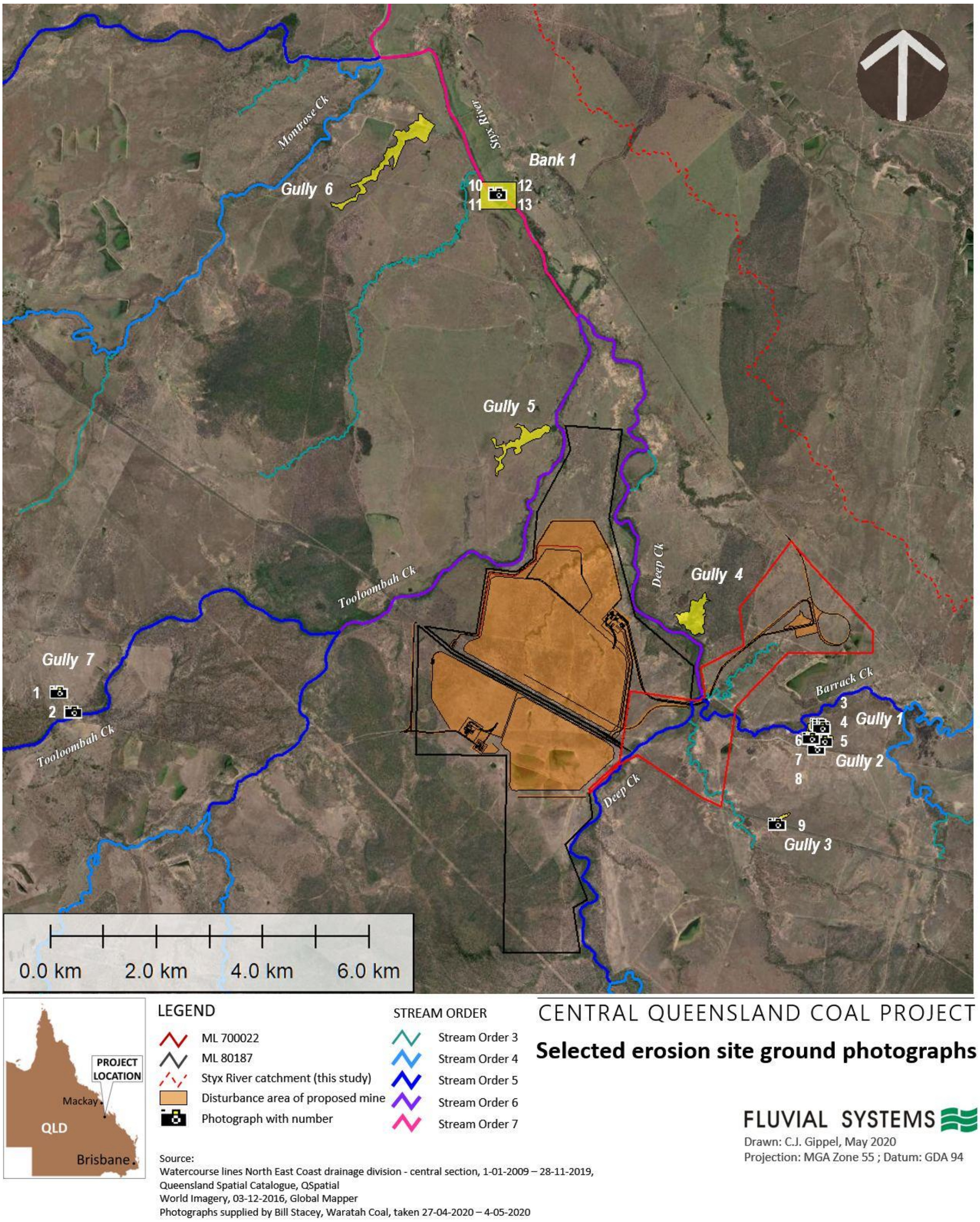
Source:
World Imagery, 03-12-2016, Global Mapper
TUFLOW hydraulic model data supplied by WRM Water & Environment Pty Ltd

Figure 37. Distribution of bed shear stress (BSS) classes, modelled for the 1% AEP flood event under the existing scenario. A small number of cells with values exceeding 500 N/m^2 were excluded as outliers.

3.3 River Bank and Gully Erosion Rates

3.3.1 Selected sites

Erosion rates were investigated at six gully sites and one river bank site (Figure 38). Gully site 7 was not analysed because of a lack of LiDAR data in that area. Gullies 4, 5 and 6 were not inspected in the field. Ground photographs were available for Gullies 1 (Figure 39), 2 (Figure 40), 3 and 7 (Figure 41). One site of notable bank erosion was investigated on the Styx River (Figure 42).



Source:
Watercourse lines North East Coast drainage division - central section, 1-01-2009 – 28-11-2019, Queensland Spatial Catalogue, QSpatial
World Imagery, 03-12-2016, Global Mapper
Photographs supplied by Bill Stacey, Waratah Coal, taken 27-04-2020 – 4-05-2020

Figure 38. Locations of selected gully and bank erosion site ground photographs.

Figure 39. Gully 1 ground photographs.

Figure 40. Gully 2 ground photographs.

Figure 41. Gully 3 and Gully 7 ground photographs.

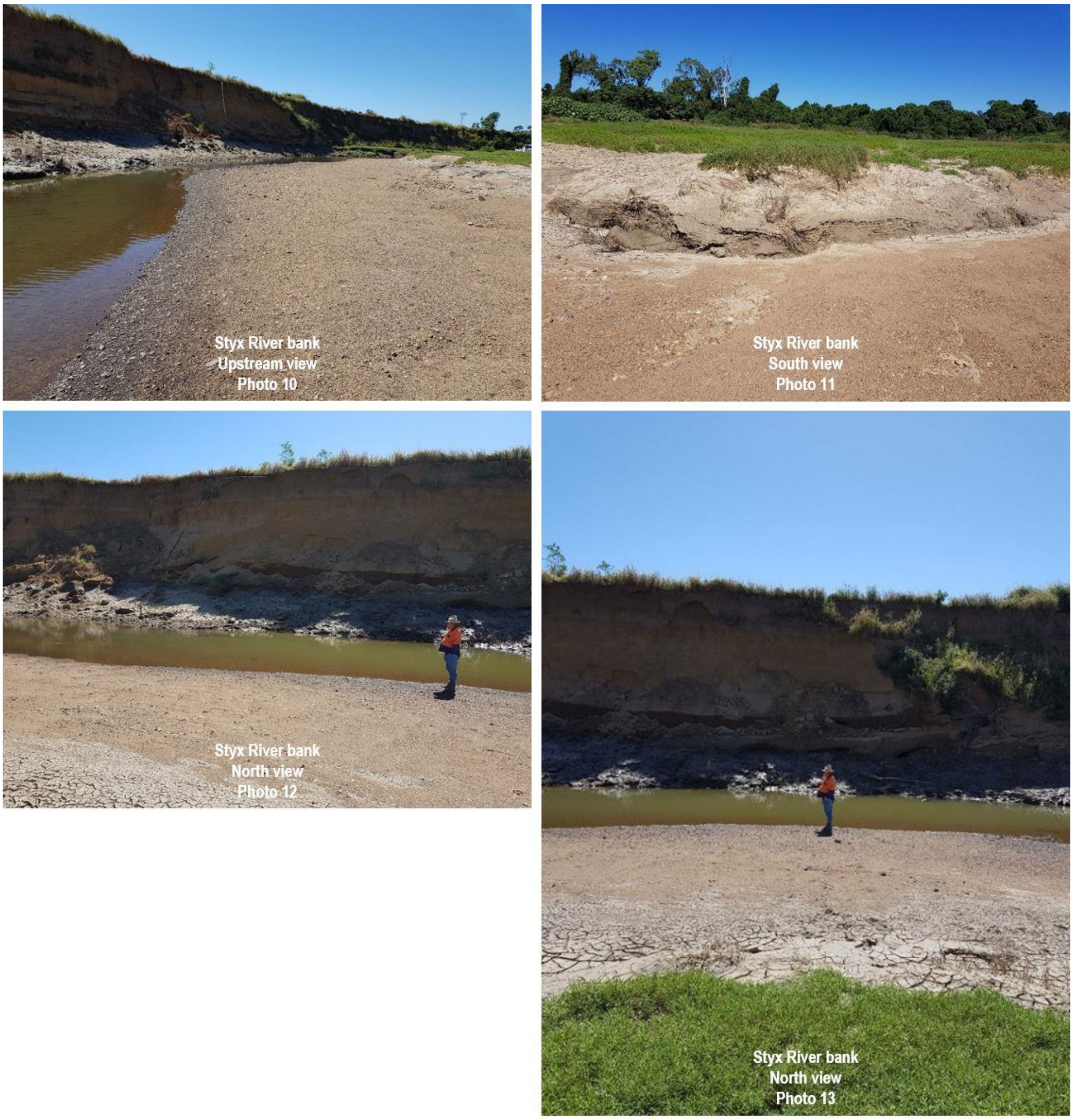


Figure 42. Styx River bank erosion site ground photographs.

3.3.2 Gully morphology

Using the alluvial gully classification system of Brooks et al. (2007), Gullies 1, 3 and 7 were linear, Gully 2 was amphitheatre, and Gully 4 was dendritic. Gullies 5 and 6 were much larger than the others, and could also have been classified as small incised tributaries. They were both linear systems, but Gully 5 also contained dendritic elements.

Gully morphology was defined using high positive profile curvature to identify sharp edges. Gully 1 had four main headcuts that migrated between the 2009 and 2011 surveys, although there were other locations on the gully system that also migrated (Figure 43). The main knickpoints were at least 1 m high, and migrated 13 to 20 m between the surveys. Gully 2 was of the amphitheatre type, but it also had at least two identifiable headcuts that migrated significant distances between the 2009 and 2011 surveys (Figure 43). Gully 3 was a small gully with one migrating headcut. The knickpoint was 1.5 m high and it migrated 30 m between the 2009 and 2011 surveys

(Figure 44). Gullies 4 (Figure 45), 5 (Figure 46) and 6 (Figure 47) did not have any edges that migrated significant distances between the 2009 and 2011 surveys.

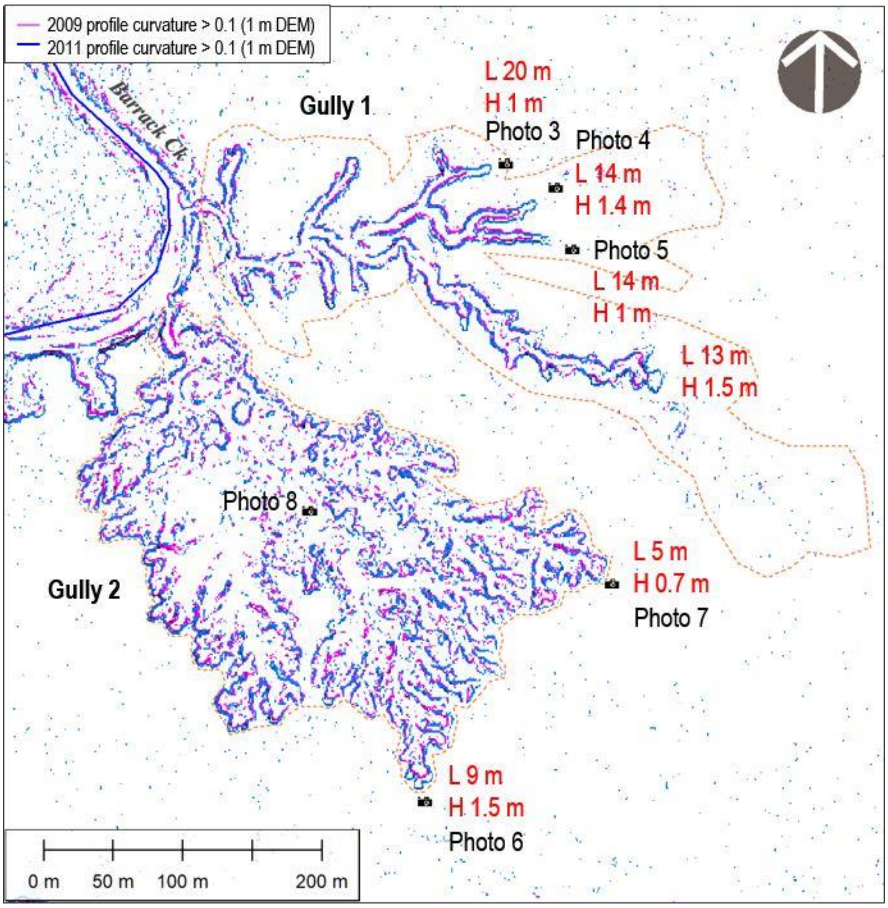


Figure 43. Gullies 1 and 2 edges defined by high profile curvature for 2009 and 2011 LiDAR. Annotations indicate height of knickpoints (H) and the distance (L) that the knickpoints migrated between the 2009 and 2011 surveys.

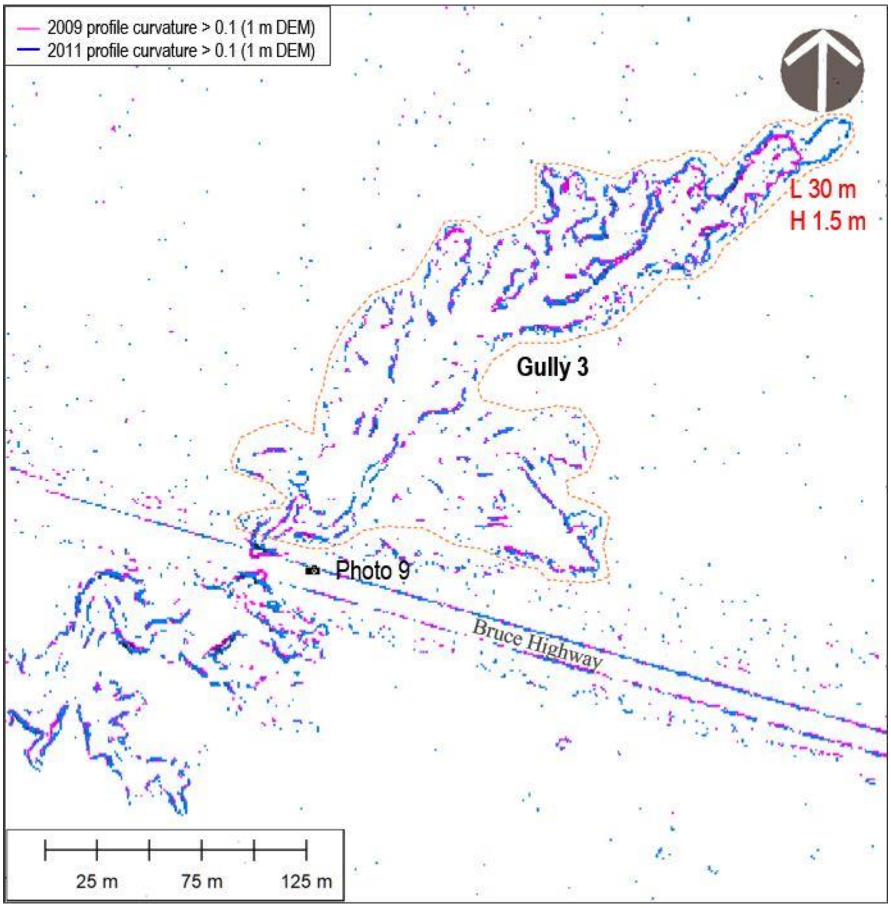


Figure 44. Gully 3 edges defined by high profile curvature for 2009 and 2011 LiDAR. Annotations indicate height of the main knickpoint (H) and the distance (L) that the knickpoint migrated between the 2009 and 2011 surveys.

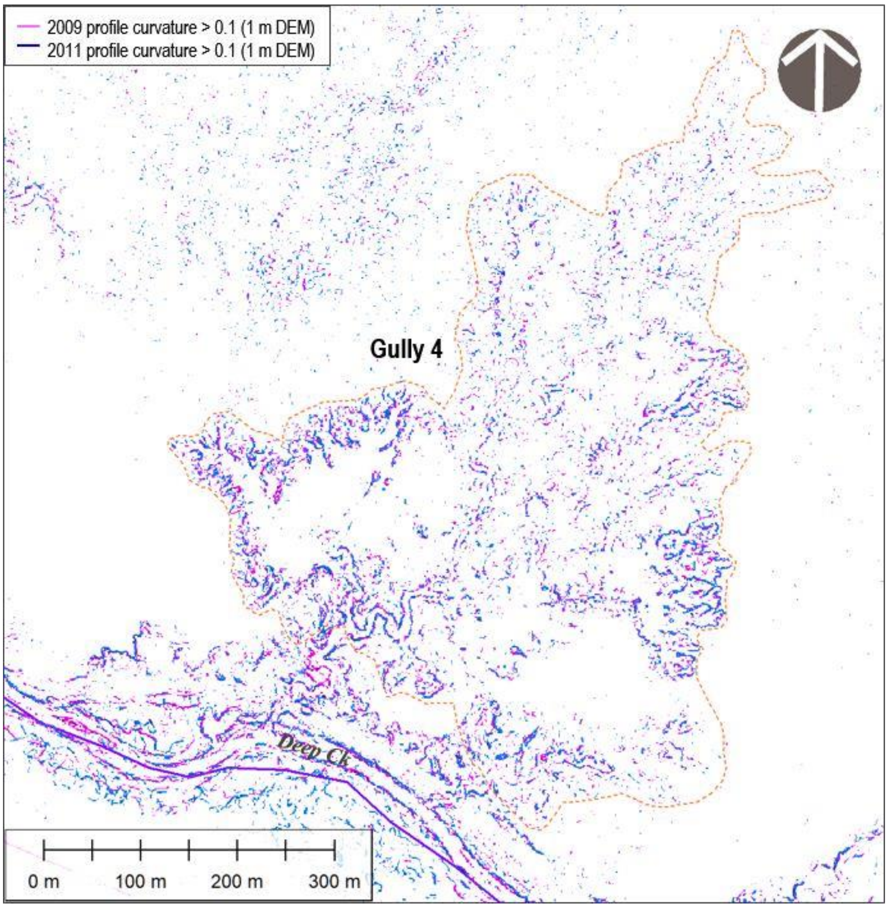


Figure 45. Gully 4 edges defined by high profile curvature for 2009 and 2011 LiDAR. None of the gully edges migrated significantly between the 2009 and 2011 surveys.

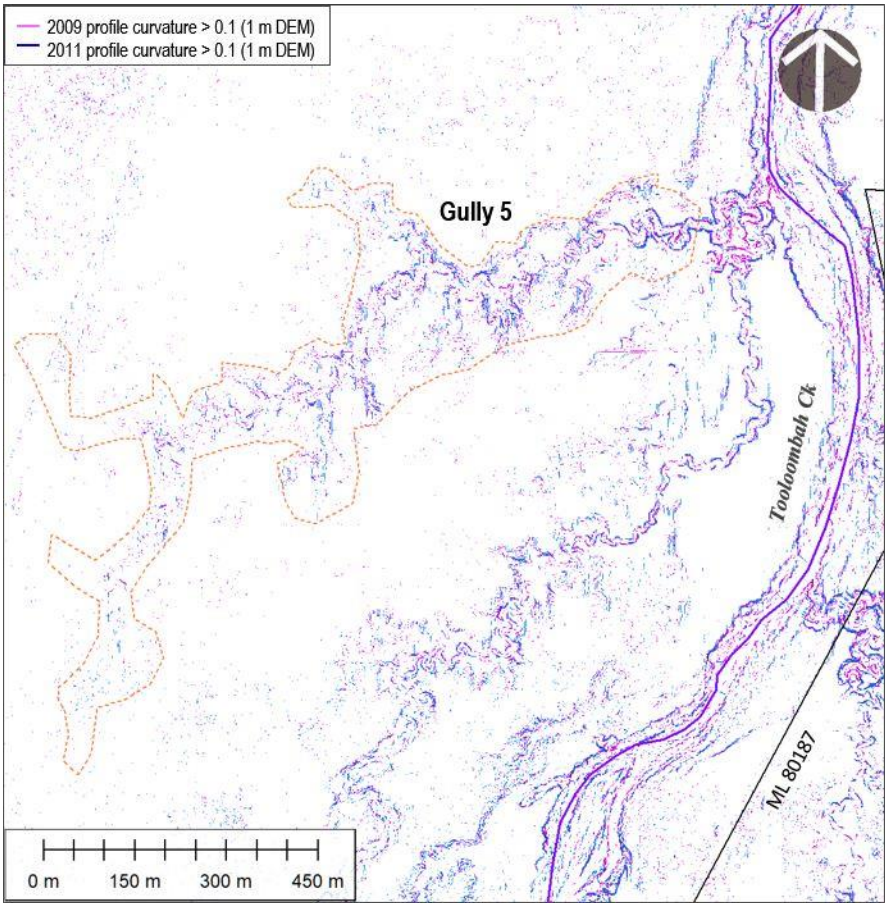


Figure 46. Gully 5 edges defined by high profile curvature for 2009 and 2011 LiDAR. None of the gully edges migrated significantly between the 2009 and 2011 surveys.

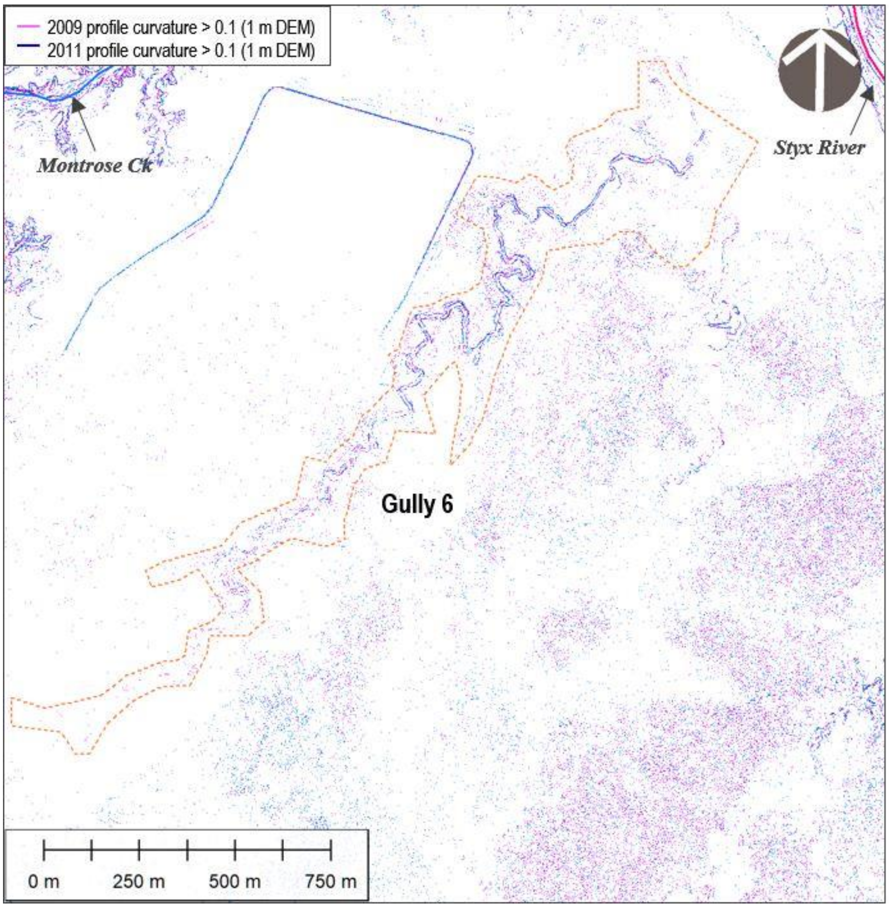


Figure 47. Gully 6 edges defined by high profile curvature for 2009 and 2011 LiDAR. None of the gully edges migrated significantly between the 2009 and 2011 surveys.

3.3.3 Gully morphological change 2009 to 2011

The mass of soil eroded from Gullies 1 – 6 between the 2009 and 22011 LiDAR surveys was estimated by measuring the mean difference in the ground elevation of the two surveys over the gully areas, and correcting this for the background difference in elevations of the two surveys. The background elevations of the two surveys differed between the sites, and also within the sites, i.e. around the perimeters of the gullies. Repeated measures of the mean differences at each gully site suggested that the error in estimation of this background difference was ±0.005 m. This was assumed to be the main source of error in the estimate of difference in gully volume between the 2009 and 2011 surveys. There would be other errors related to point cloud density and incorrect classification of points, but these would have been difficult to estimate. Volume of eroded material was converted to mass assuming a specific gravity of 2.65, i.e. the eroded material was assumed to be all mineral, with low void space.

The yield of eroded material varied over a wide range across the six gullies (Table 25). The highest yield was from Gully 2, with a globally very high annualised rate of soil loss of 2,670 t/ha/yr. Gullies 1, 3 and 4 also produced high yields of sediment, with annualised rates of soil loss of 1,049, 732, and 558 t/ha/yr. Gullies 5 and 6 were relatively benign, with Gully 5 effectively stable (within error bounds), and Gully 6 having a small positive yield.

Table 25. Area, and change in mean elevation, volume and mass of gullies between 2009 and 2011 LiDAR surveys.

Variable	Gully 1	Gully 2	Gully 3	Gully 4	Gully 5	Gully 6
Gully area (m^2)	63,751	64,779	25,237	249,044	239,526	450,933
LiDAR background elevation difference 2011-2009 (m)	0.02213 ±0.005	0.01286 ±0.005	0.02648 ±0.005	-0.04910 ±0.005	0.06518 ±0.005	-0.08931 ±0.005
Corrected mean gully elevation difference 2011-2009 (m)	-0.03513 ±0.005	-0.10986 ±0.005	-0.02114 ±0.005	-0.02790 ±0.005	-0.00318 ±0.005	-0.00569 ±0.005
Volume eroded 2009-2011 (m^3) [range incorporates error]	4,365 3,743-4,986	11,285 10,771-11,799	1,205 920-1,490	9,061 7,437-10,685	1,472 -845-3,788	3,763 457-7,070
Annualised mass erosion rate (t/ha/yr) [range incorporates error]	1,049 900-1,199	2,670 2,549-2,792	732 559-905	558 458-658	94 -54-242	128 16-240

3.3.4 Styx River bank morphological change 1953 – 2018

At the site under investigation just downstream of Ogmore Road bridge, the 1953 aerial photograph shows the left bank of the Styx River densely forested, and the right bank cleared (Figure 48). By 1975 the majority of the left bank in this area had also been cleared, but the uncleared patches of vegetation remained intact until 2018. By 1985 the toe of the right bank and the low flow channel had migrated to the right. By 2004 the top of the bank on the bend had reached the edge of the track that was formerly ~20 m from the edge. By 2016 the track had been moved inland and the top and toe of the bank had migrated a significant distance to the right. There appears to have been little to no change between 2016 and 2018 (Figure 48).

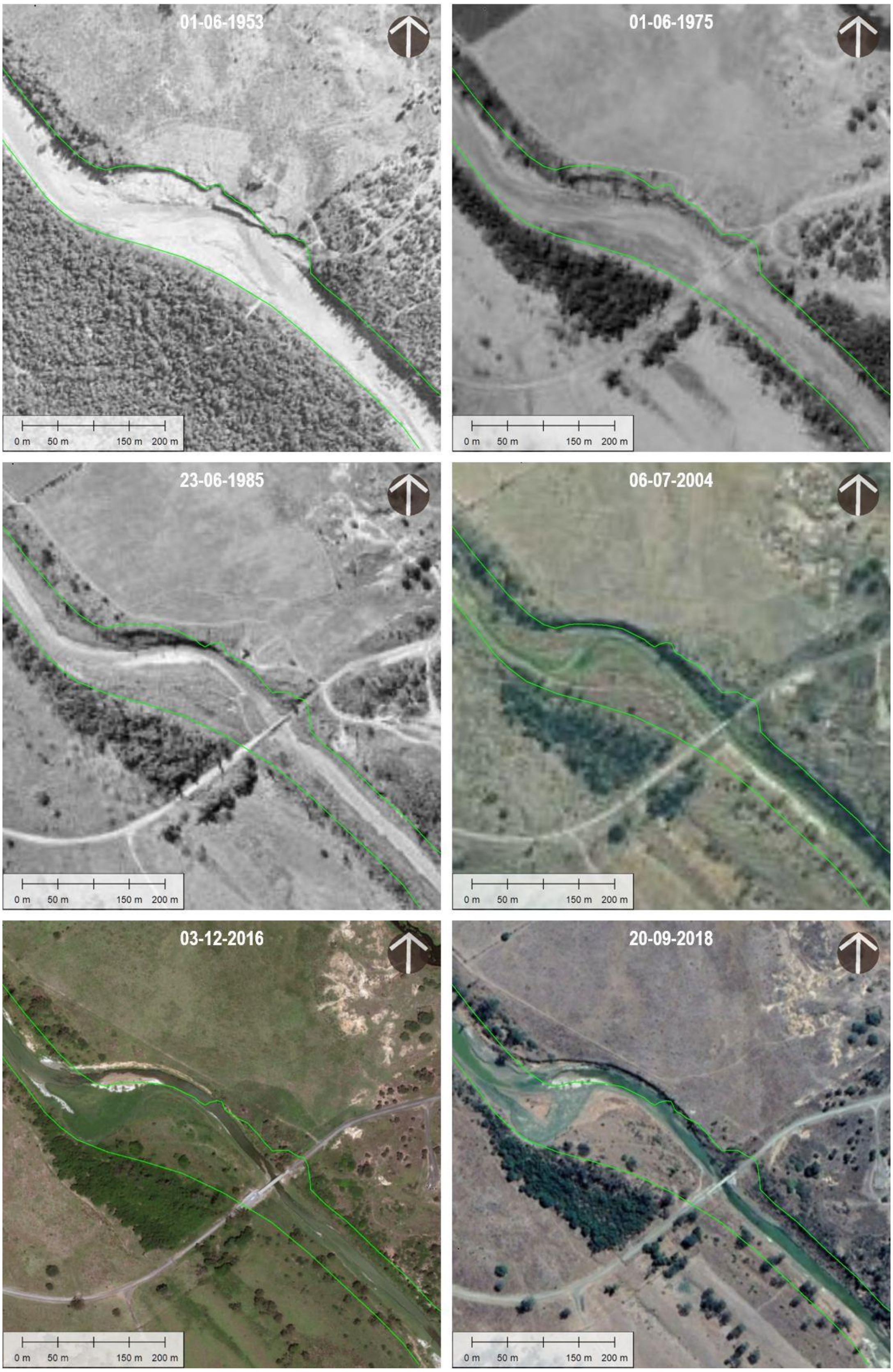


Figure 48. Bend on the Styx River just downstream of Ogmore Road Bridge as it appears on rectified aerial photographs from 1953 to 2018.

3.3.5 Styx River bank morphological change 2009 – 2011

High positive profile curvature clearly delineated the bank tops of the Styx River at the site under investigation just downstream of Ogmore Road bridge (Figure 49). The high profile curvature rasters were automatically converted to vectors that marked the top of bank edge (Figure 50). In this area, the elevation of the cleared flat land on the top of the right bank of the river that was unaffected by erosion was on average 0.162 m higher on the 2009 LiDAR than on the 2011 LiDAR. A correction was made to the data prior to subtracting the 2009 and 2011 DEMs. A comparison of the LiDAR data indicated that over the 259 m long eroded section, which had a mean bank height of 8.5 m, the mean eroded width was 8.2 m (maximum 16 m) and total volume eroded was 18,056 m^3. This compares to a total of 31,151 m^3 eroded from the 6 gullies over the same period (Table 25). It appears that about half of the bank migration that has occurred in this location between 1953 and 2018 (up to about 30 m) occurred between 2009 and 2011 (Figure 50).

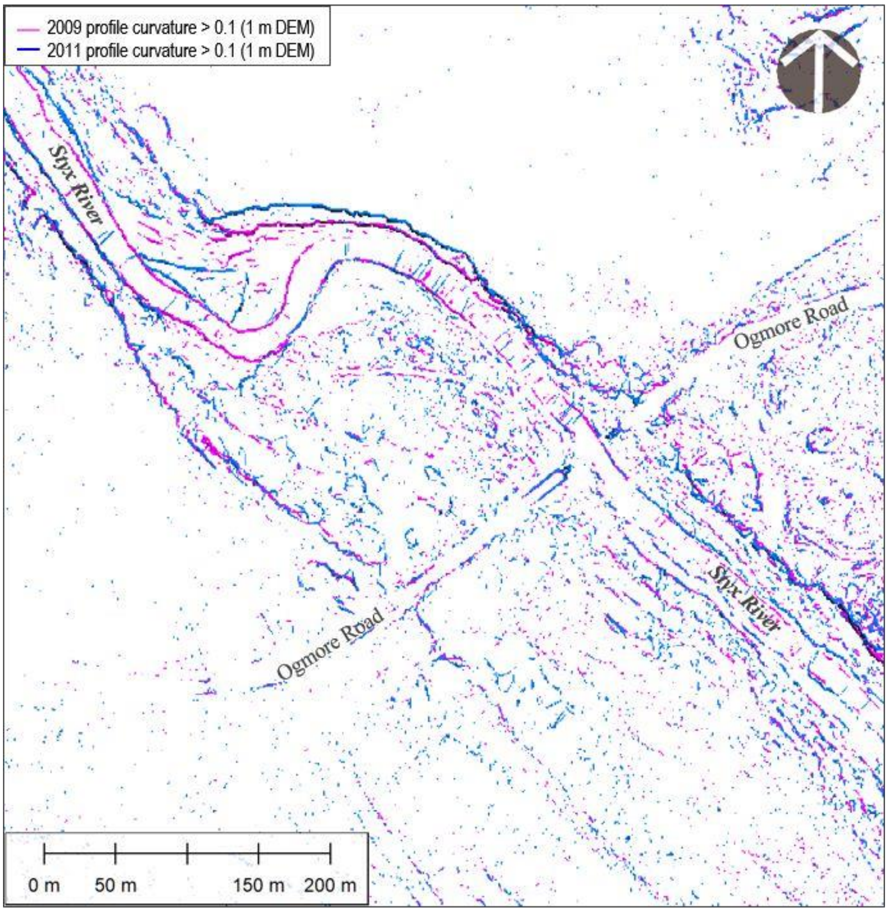


Figure 49. Morphology of the bend on the Styx River just downstream of Ogmore Road Bridge defined by high profile curvature for 2009 and 2011 LiDAR.

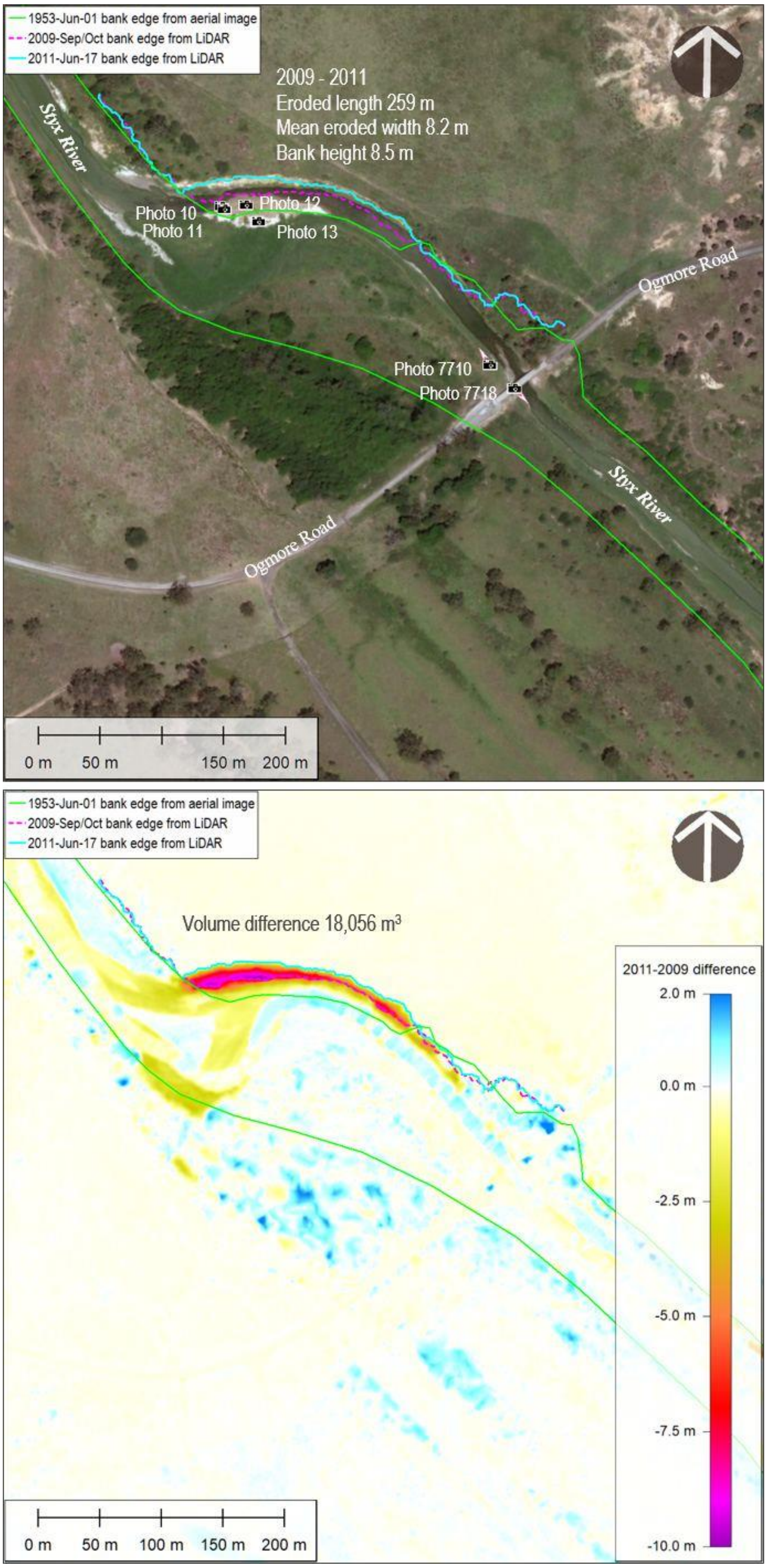


Figure 50. Morphology of the bend on the Styx River just downstream of Ogmore Road Bridge, showing 2009 and 2011 bank top edges automatically defined by profile curvature (top) and 2009 to 2011 eroded volume difference automatically calculated from the LiDAR elevation data (bottom).

4.0 Impact assessment

4.1 Hydrologic and Hydraulic Impacts

4.1.1 Drainage flow paths and flood extents under Existing and Developed (P8) scenarios

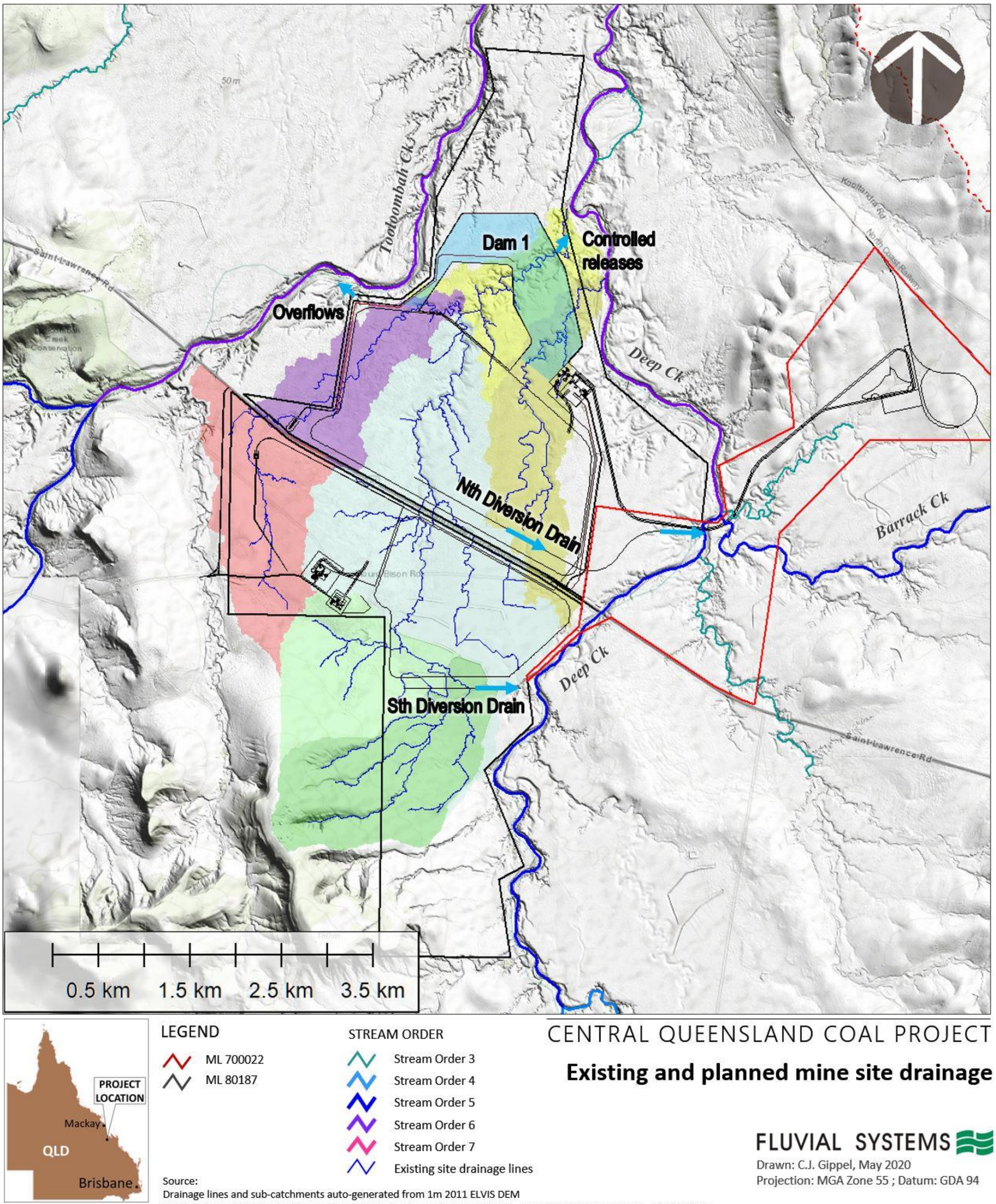
The mine surface water arrangement was described by WRM Water & Environment (2020) (Figure 51). The main hydrologic impact during the early stages of development (up to and including P8) would be diversion of the southern catchment area via the Northern Diversion Drain to Deep Creek, just upstream of Barrack Creek junction. The majority of the remainder of the catchment area would discharge to Dam 1, which would then be managed to deliver the collected runoff to the tributary creek that currently discharges water from this catchment to Deep Creek. Dam 1 would have an overflow discharge to Tooloombah Creek. Under Existing conditions, the two most western sub-catchments that drain to the mine site (mauve and peach coloured sub-catchments in Figure 51) flow in a northeast direction and discharge to Deep Creek. Under the developed scenario, the flow from these sub-catchments would be diverted northwards around the western boundary of the mine to discharge to Tooloombah Creek (Figure 51).

While the total amount of surface water discharging from the mine area to Deep Creek would be little changed, its distribution and timing would be altered. From the outflow of the Northern Diversion Drain to the outflow from Dam 1, Deep Creek would have slightly higher storm flow than under the existing situation. From the outflow from Dam 1, Deep Creek would generally have slightly lower storm flow than under the existing situation, but periodically flows would be higher when controlled releases were made from Dam 1. Open Cut 1 would be active from 2029 onwards, at which time the Southern Diversion Drain would become active. The Developed Stage P8 was evaluated here, during which time the Northern Diversion Drain would be active.

Maps of flood inundation extent for the 10% AEP (Figure 52) and 1% AEP (Figure 53) flood events illustrate how the surface water management arrangements direct floodwater from sub-catchments, and overbank flow from Deep Creek in the case of the 1% AEP event, around the mine site. The redistribution of these flows would have negligible impact on the extent of flood inundation of the floodplains of Deep Creek, Tooloombah Creek and Styx River (Figure 52 and Figure 53).

4.1.2 Distribution of velocity under the Developed (P8) scenario

For areas inundated under both the Existing and Developed P8 scenarios there was negligible difference in velocity distribution. Under both the 10% AEP and 1% AEP events, areas inundated under the Developed scenario, but not the Existing scenario, i.e. the Northern Diversion Drain, and the western sub-catchments, had velocities generally less than 1 m/s (Figure 54 and Figure 55), which would be stable under good grass cover (Table 18). The exceptions were under the 1% AEP event: (i) in the 400 m-long area where drainage from the western sub-catchments concentrates and then discharges to Tooloombah Creek, and (ii) where sub-catchments upstream of the mine discharge to the Northern Diversion Drain (Figure 55). In these areas, velocity is greater than 1 m/s but less than 2 m/s. These area will require maintenance of good vegetation cover and regular monitoring of stability, plus preparation of a plan to fortify them with rock rip-rap should significant incision occur. The end of the Northern Diversion Drain where it discharges to Deep Creek has a short section where velocity exceeds 2 m/s (Figure 55). To ensure stability, this section of the Drain will require fortification with rip-rap.



Source:
Drainage lines and sub-catchments auto-generated from 1m 2011 ELVIS DEM
Third Order and higher watercourse lines North East Coast drainage division - central section, 1-01-2009 – 28-11-2019, Queensland Spatial Catalogue, QSpatial

Figure 51. Proposed mine water management arrangements. Based on information in WRM Water & Environment (2020).

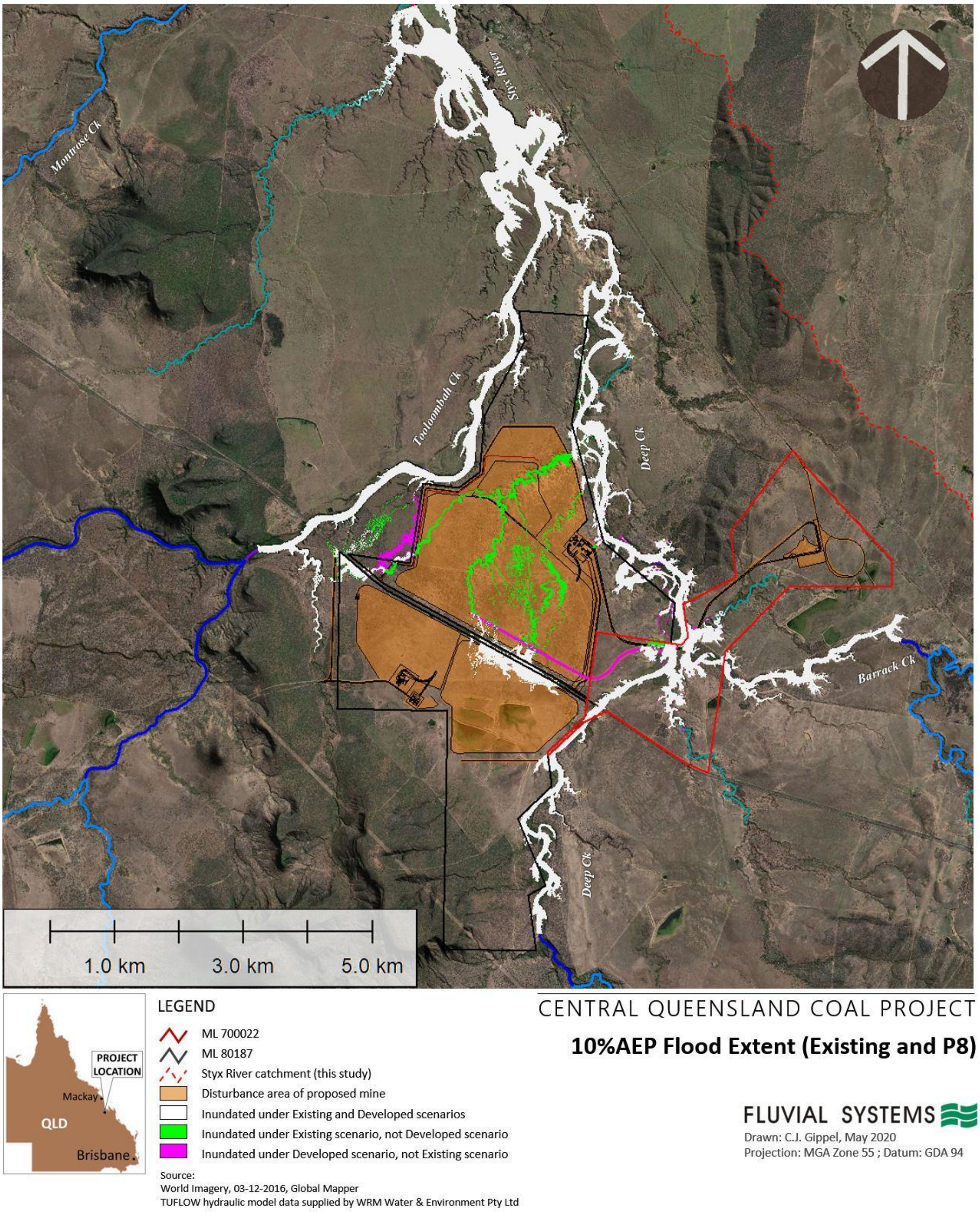
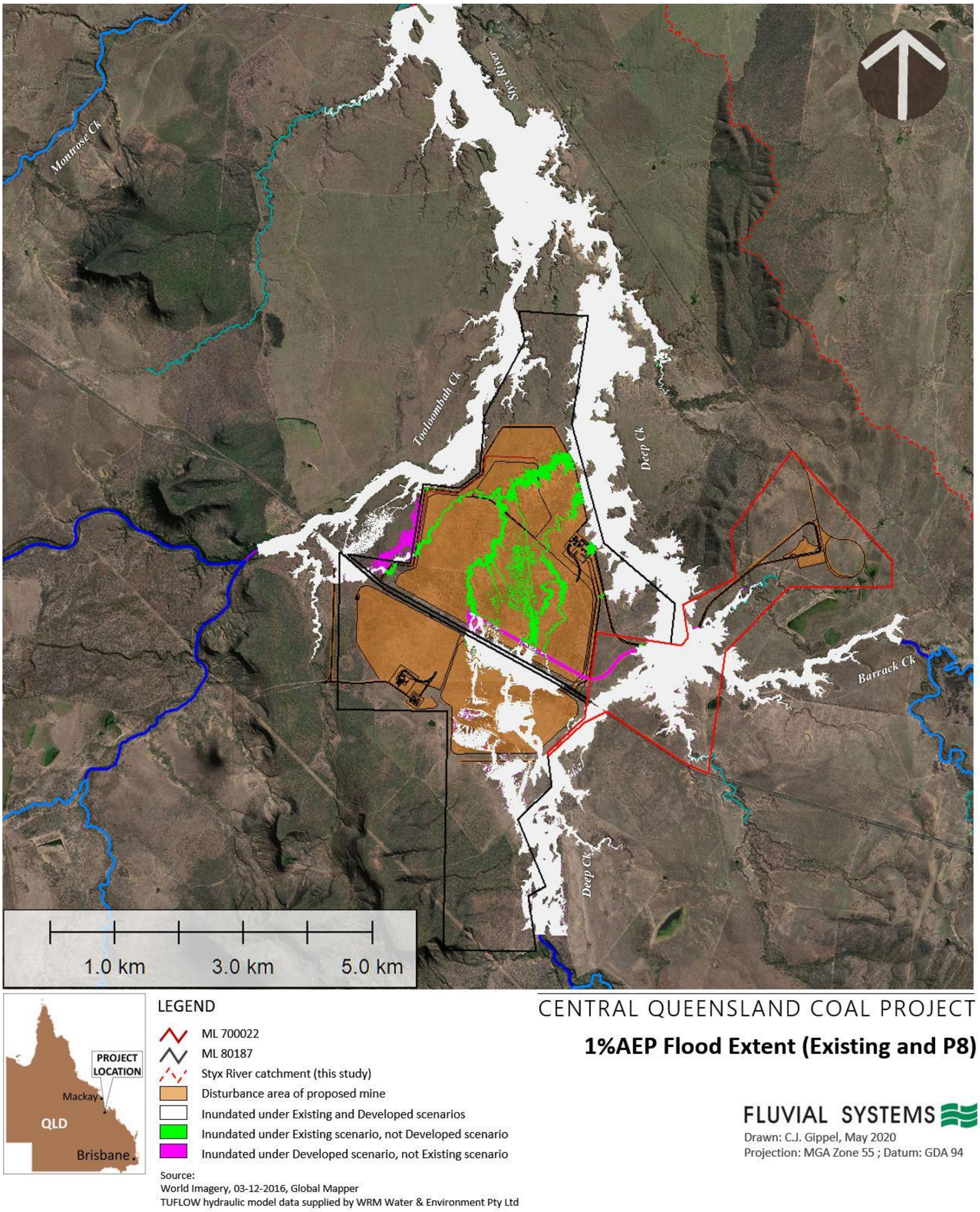


Figure 52. Modelled 10% AEP flood inundation extent under Existing and Developed P8 scenarios.



Source:
World Imagery, 03-12-2016, Global Mapper
TUFLOW hydraulic model data supplied by WRM Water & Environment Pty Ltd

Figure 53. Modelled 1% AEP flood inundation extent under Existing and Developed P8 scenarios.

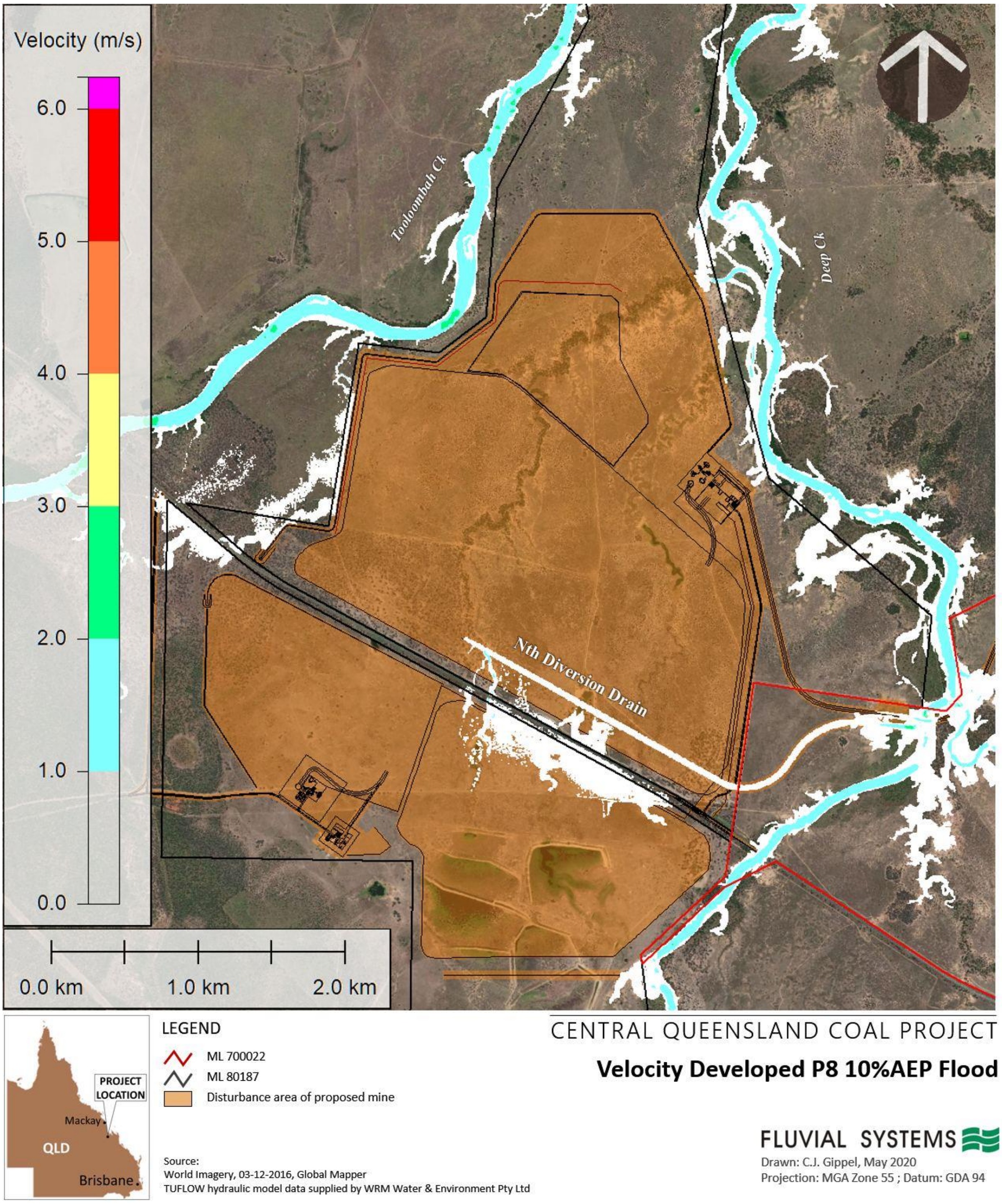
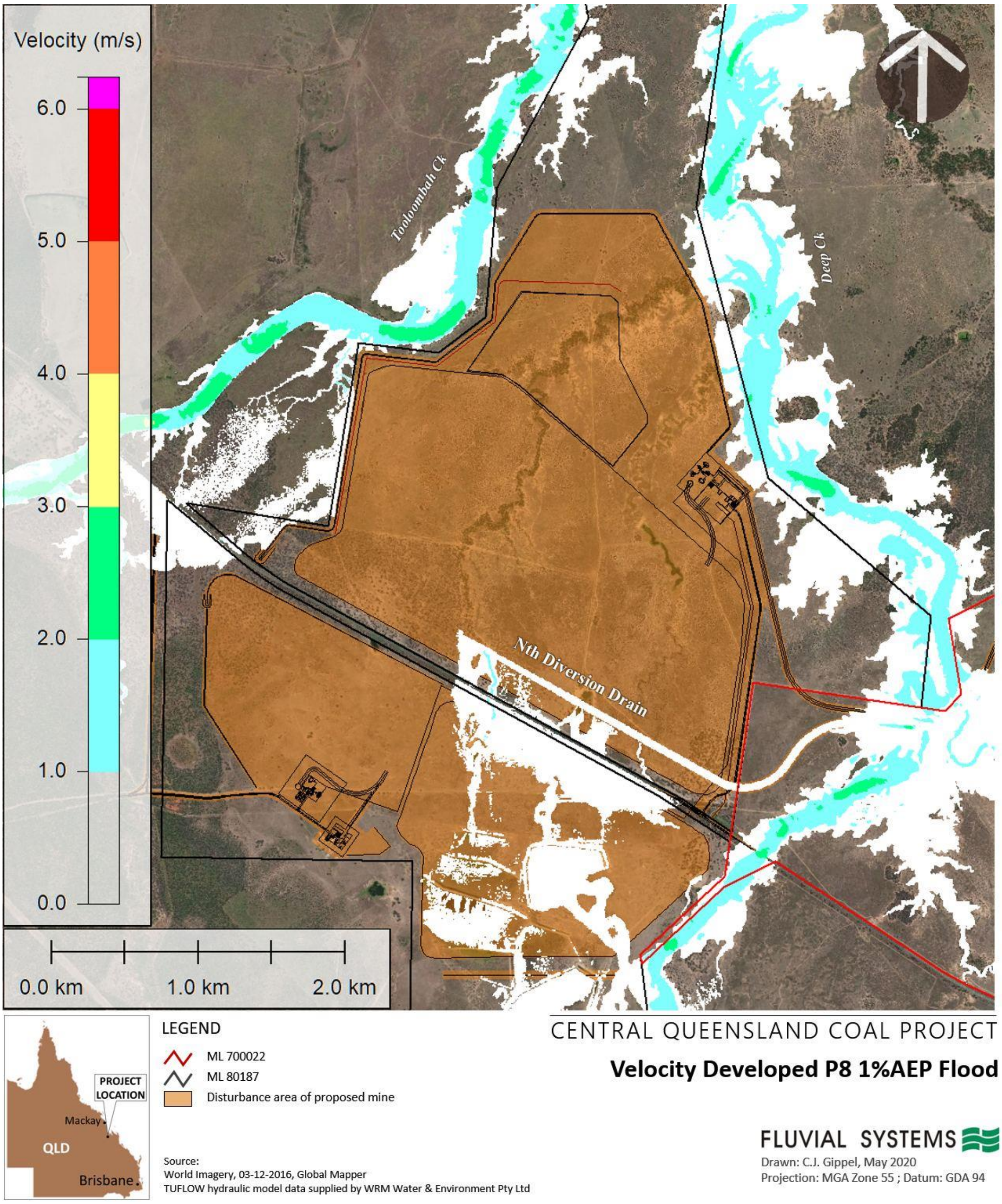


Figure 54. Modelled 10% AEP velocity under Developed P8 scenario. A small number of cells with values exceeding 4 m/s can be considered outliers.



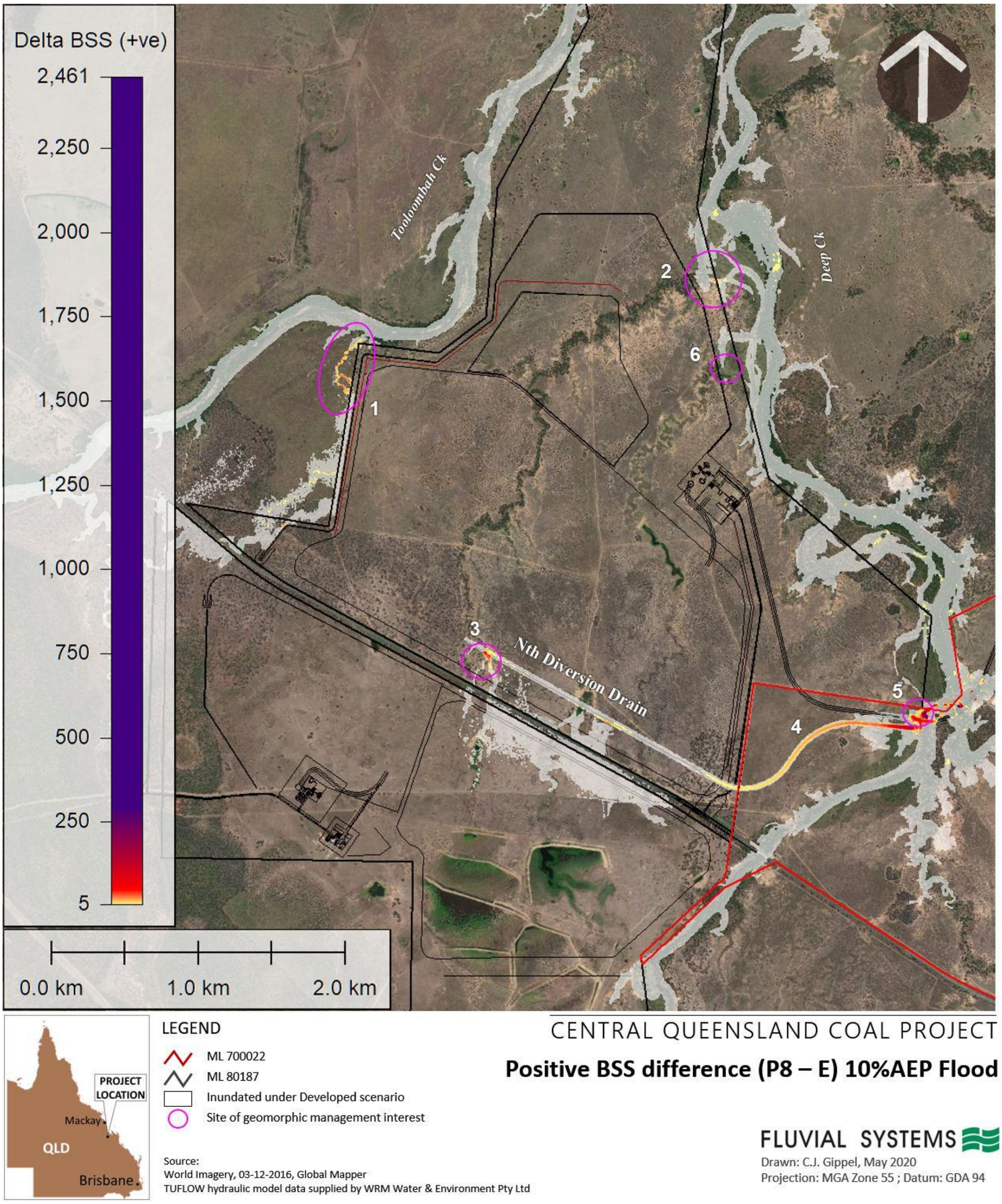
Source:
World Imagery, 03-12-2016, Global Mapper
TUFLOW hydraulic model data supplied by WRM Water & Environment Pty Ltd

Figure 55. Modelled 1% AEP velocity under Developed P8 scenario. A small number of cells with values exceeding 4 m/s can be considered outliers.

4.1.3 Distribution of bed shear stress (BSS) under the Developed (P8) scenario

For areas inundated under both the Existing and Developed scenarios, as with velocity, there was negligible difference in bed shear stress (BSS) distribution. One notable exception was at the proposed rail bridge crossing over Deep Creek (Site 6 in Figure 56 and Figure 57). The bed shear stress at the bridge crossing was over 2000 N/m^2 under the 10% AEP event (Figure 56). Bed scour could be expected at this location. Under the 10% AEP and 1% AEP events, areas inundated under the Developed scenario, but not the Existing scenario, i.e. the

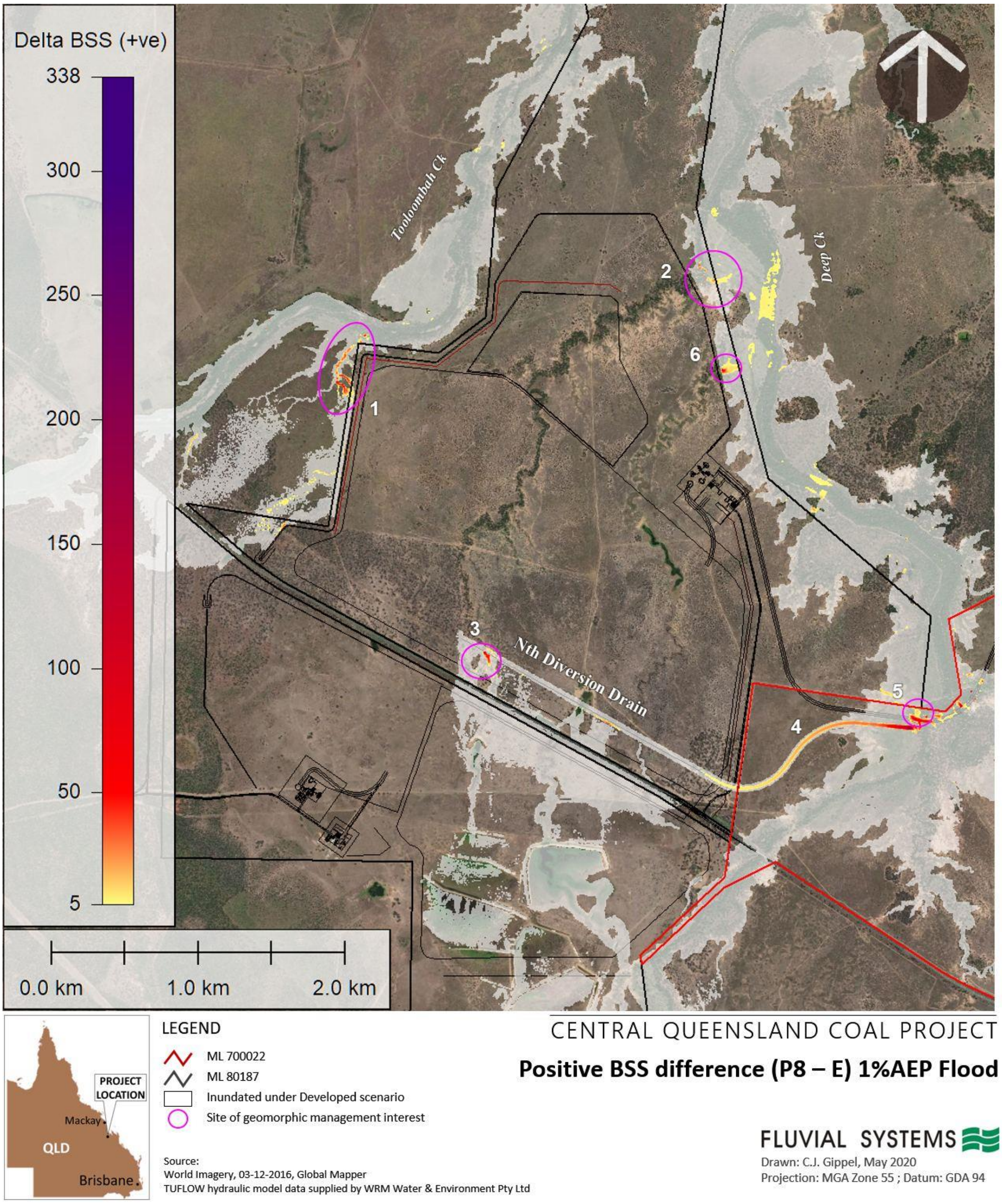
Northern Diversion Drain, and the western sub-catchments, had BSS values generally less than 200 N/m^2 (Figure 56 and Figure 57), which would be stable under good grass cover (Table 18).



Source:
World Imagery, 03-12-2016, Global Mapper
TUFLOW hydraulic model data supplied by WRM Water & Environment Pty Ltd

Drawn: C.J. Gippel, May 2020
Projection: MGA Zone 55 ; Datum: GDA 94

Figure 56. Difference in modelled 10% AEP BSS for Developed P8 and Existing scenarios. Only positive differences are shown.



Source:
World Imagery, 03-12-2016, Global Mapper
TUFLOW hydraulic model data supplied by WRM Water & Environment Pty Ltd

Figure 57. Difference in modelled 1% AEP BSS for Developed P8 and Existing scenarios. Only positive differences are shown.

Six locations were highlighted where the BSS values associated with the Developed P8 scenario were high enough to warrant monitoring and/or mitigation.

1. The 400 m-long area where drainage from the western sub-catchments concentrates, then discharges to Tooloombah Creek.
2. Discharge channel from Dam 1 to Deep Creek.

3. Where sub-catchments upstream of the mine discharge to the Northern Diversion Drain.
4. The Northern Diversion Drain, particularly the lower 500 m.
5. At the proposed rail bridge crossing over Deep Creek.
6. An isolated location near Dam 1 wall.

Sites 1 and 3 are risk areas for gully formation. They will require maintenance of good vegetation cover and regular monitoring of stability, plus preparation of a plan to fortify them with rock rip-rap should significant incision occur. Site 4, the lower end of the Northern Diversion Drain where it discharges to Deep Creek, will require fortification with rip-rap. Site 2 is likely to require fortification with rip-rap to eliminate the risk of formation of knickpoints that could migrate towards Dam 1 embankment. This is a risk with a high consequence. Site 5, at the proposed rail bridge crossing over Deep Creek, was predicted to experience bed scour. This risk can be managed by designing the bridge crossing in accordance with civil engineering design standards.

Site 6 was an isolated area about 50 × 50 m near Dam 1 wall with modelled increase in BSS and velocity for the 1% AEP event. Under the 1% AEP event this area was inundated to a depth of about 1 m, but it was not inundated under the 10% AEP event. Examination of the topography and modelled flood water levels revealed this risk area to be a localised high point where under the P8 scenario the flood water surface fell 0.13 m over a distance of 50 m. Under the Existing scenario, 1% AEP floodwaters would spread westward into the small creek, and the fall in water surface elevation was only 0.04 m. Confinement due to the dam wall locally increasing the water surface slope explained the increased BSS and velocity in this location. Even so, under the P8 scenario, the BSS at Site 6 was less than 80 N/m^2 and velocity was less than 1.7 m/s, so provided this area remains vegetated, the risk of scour of the surface would be low (Table 18).

4.2 Sodicity of Waste Rock

Waste rock comprises overburden and interburden material extracted as part of mining operations. Waste rock generally consists of large sized, blocky material. CDM Smith (2018d, p. 8-35) analysed and classified composite waste rock and potential coal reject samples in accordance with the indicative criteria for saline and sodic material. The salinity classification was medium, while the sodicity classification was very high. This was confirmed by RGS Environmental (2020).

Sodicity of waste rock and coal reject composite samples were very high, with Exchangeable Sodium Potential (ESP%) in the range 28.9% to 42.7%. According to the standard criteria, values of ESP% greater than 20% are considered very high. As pointed out by CDM Smith (2018d, p. 8-35), strongly sodic materials are likely to be dispersive and have problems with structural stability. In addition, sodic materials often have unbalanced nutrient ratios that can lead to macro-nutrient deficiencies, so often require the addition of fertilisers for successful rehabilitation. The soil management and rehabilitation procedures described in Chapter 11 of SEIS Version 3 (CQC, 2020), RGS Environmental (2020) and Engeny Water Management (2020a) address the issue of management of waste rock.

4.3 Potential Sediment Loads

The average total sediment (TSS) load of the entire Fitzroy Basin (139,159 km^2 monitored area) over the 7 year period 2009/10 to 2015/16 was 6,821,429 tonne (Table 5-40 in CDM Smith, 2018, p. 5-92). This equates to a mean specific sediment yield of 0.164 t/ha/yr. Consistent with this, Bartley et al. (2017) quoted average measured TSS load for the Fitzroy River at Rockhampton of 2,300,000 tonnes per year, which equates to a mean specific sediment yield of 0.17 t/ha/yr. The modelled mean specific sediment yield from the Styx catchment was 0.3 t/ha/year (Bartley et al., 2017).

CDM Smith (2018b) made an assessment of the sediment loads generated from the Mamelon property under the current grazing land use. Shellberg and Brooks (2013) were quoted as reporting cattle grazing as a primary agent for accelerating gully erosion on highly-erodible sodic soils. Central Queensland Coal has committed to destocking the majority of the Mamelon property, which, along with implementation of engineered erosion and sediment controls, CDM Smith (2018) predicted would result in reduced sediment load to the Styx River, and thus, to the GBR.

Given the lack of local data for the Styx catchment, CDM Smith (2018b) estimated erosion for land under grazing using the HowLeaky? model developed for the Eden Bann Weir EIS. This model used best available soil, vegetation and soil nutrient information for two representative soil types at Yaamba and Rockwood in Central Queensland. Land use and management comprised three grazing regimes to represent potential current land use practice. The model used estimates of sediment yield from floodplain land for these three grazing regimes. Low stocking pasture 44% October yielded 0.34 t/ha/yr, Moderate stocking pasture 34% October (C) yielded 0.72 t/ha//yr, and Excess stocking pasture 20% October (D) yielded 1.6 t/ha/yr. On upland slopes, Moderate stocking pasture 34% October (C) yielded 1.9 t/ha/yr (CDM Smith, 2018b, Table 5-42, p. 5-95). In *Table 5-45 Estimated annual pollutant load for ML 80187* and *Table 5-46 Estimated annual pollutant load for ML 700022*, CDM Smith (2018b, p. 5-98) multiplied these specific yield estimates by the surface area of ML 80187 (1,748 ha of floodplain and 121 ha of upland slopes) and by the surface area of ML 700022 (535 ha of floodplain and 52 ha of upland slopes) to give total load of sediment per year. These tables express the result in t/ha, but this appears to be an error, as the load would be in tonnes per year. The values range from 595 to 2,797 for floodplain land on ML 80187, and 182 to 856 for floodplain land on ML 700022. Engeny Water Management (2020b) recalculated the existing sediment load using the same specific yield estimates quoted by CDM Smith (2018b), arriving at averages of 4,500 t/yr from Mamelon property, and 537 t/yr from ML 700022, for a total of 5,037 t/yr. This equates to an average existing specific yield of 0.72 t/ha/yr.

CDM Smith (2018b, p. 5-123 to 5-126) applied a RUSLE model to estimate sediment soil loss from the Mamelon property under conditions of construction disturbance. The results indicated mean specific sediment yield of 67 to 1,392 t/ha/yr. CDM Smith (2018b) proposed that with engineering sediment and erosion controls, this could be reduced to 3 to 70 t/ha/yr. These would be considered very high rates of sediment yield. Engeny Water Management (2020b) re-calculated the average annual sediment loss from the majority of the disturbance area (1,272 ha) under worst-case operational conditions to be 219,570 tonne, which equates to a specific sediment yield of 173 t/ha/yr. The average specific yields from 6 sub-areas ranged from 53 to 420 t/ha/yr. It was pointed out by Engeny Water Management (2020b) that these were conservative estimates and actual sediment loss from the waste rock dump slopes was proposed to be mitigated by a number of controls.

Engeny Water Management (2020b) estimated the worst-case operational mean specific sediment yield with adopted controls in place over the combined Mamelon property, offset areas within the Mamelon property, and disturbance area. The total was 2,297 t/yr, or mean specific sediment yield of 0.37 t/ha/yr. This represents an approximate halving of the sediment yield compared to the existing scenario.

The conceptual Erosion and Sediment Control Plan produced by Engeny Water Management (2020a) pointed out that CQC intends to destock the majority of the Mamelon property to allow for the natural regeneration of vegetation. It was assumed this would reduce sediment generation from the Project area as the vegetation communities within the riparian corridors regenerated without being subjected to ongoing grazing pressures. Otherwise, the Plan focused on erosion and sediment control measures during construction and operation phases of the mine.

5.0 Monitoring and Mitigation

5.1 Monitoring

Geomorphic monitoring should be undertaken using objective, scientifically sound methods, following a BACI (Before/After/Control/Intervention) design. Also, the monitoring should target areas where this assessment predicted the risk of geomorphic instability would be greatest (Table 26). The foundation of the recommended approach to monitoring is topographic survey at targeted risk areas, repeated every year for 3 years, and then either every five years, or after every flood event exceeding the 5 yr ARI event. Ideally this should be done using LiDAR technology, although intensive ground survey would also be acceptable. It will be necessary to identify control reaches that are also monitored, away from the influence of the CQC Project. The monitoring principle is to characterise the degree of change at the control areas and use this to set the tolerance for change in the target areas. After each survey, a monitoring report is to be prepared that uses scientific methods to evaluate the data, including statistical analysis to test for significance of differences across a range of geomorphic variables derived from the survey data.

Methods that rely only subjective visual assessments of geomorphic variables (e.g. erosion severity, or geomorphic condition score sheets) are not recommended, as in general, they are not founded on a sound basis of geomorphic theory, do not utilise a scientifically valid sampling strategy, observations are not repeatable within acceptable tolerances, and the data are not open to rigorous statistical testing. However, regular (monthly) visual inspections that involve fixed photo points and completion of standard documentation could support the less frequent survey data by potentially providing early detection of change.

Table 26. Target sites for geomorphic process monitoring and mitigation.

Site	Location	Mitigation	Monitoring
1.	The 400 m-long area where drainage from the western sub-catchments concentrates, then discharges to Tooloombah Ck	Ensure good vegetation cover	YES
2.	Discharge channel from Dam 1 to Deep Creek	Rip-Rap	YES
3.	Where sub-catchments upstream of the mine discharge to the Northern Diversion Drain	Ensure good vegetation cover	YES
4.	The Northern Diversion Drain, particularly the lower 500 m (likely to also apply to the Southern Diversion Drain)	Construct to civil engineering design	YES
5.	At the proposed rail bridge crossing over Deep Creek	Construct to civil engineering design	YES
6.	An isolated location near Dam 1 wall.	Ensure good vegetation cover	YES

5.2 Mitigation

Mitigation is to eliminate or reduce the frequency, magnitude, or severity of exposure to risks, or to minimise the potential impact of a threat. Mitigation of the impacts of accelerated sediment delivery to the drainage system, and then to the Great Barrier Reef is an established objective (Department of Agriculture, Water and the Environment, 2018). This can be achieved through vegetation management, maintaining complete vegetation cover over hillslope, river bank and floodplain surfaces. Grass provides good resistance to erosion on hillslopes and small gently sloping drainage channels, but forest, with tree, shrub and ground cover, is preferable on steep land, larger drainage channels and river banks.

In general, the surface water management works should follow standard civil engineering design principles. All diversion drains and diversion banks will be designed with geotechnically and erosionally stable batter slopes (Engeny Water Management, 2020a).

This report draws particular attention to the need for fortification of the outlet from Dam 1 to Deep Creek, and the lower 500 m of the Northern Diversion Drain (Sites 2 and 4 in Table 26). This report also draws particular attention to the 400 m-long area where drainage from the western sub-catchments concentrates and then discharges to

Tooloombah Creek, where sub-catchments upstream of the mine discharge to the Northern Diversion Drain, and an isolated location near Dam 1 wall, which will require maintenance of good vegetation cover in order to remain at low risk of surface scour (Sites 1, 3 and 6 in Table 26).

The need for application of mitigation measures over the life of the mine would be triggered by unexpectedly large change in morphology identified through monitoring. The most appropriate response would need to be assessed at the time.

6.0 Conclusion

Repeatable methods were used to characterise geomorphological attributes of the CQC Project area. Most of the stream reaches were in a stable, moderate geomorphic condition. One migrating bend on the Styx River was identified as a significant source of sediment to the river. No knickpoints or zones of major geomorphic instability were observed on the mapped watercourses. However, the area contains a significant number of alluvial gullies and small tributaries incised into old alluvium. These are potentially sources of high sediment loads to the river system, and thus the Great Barrier Reef.

The risk of erosion of the channels and floodplains was assessed using the method of maximum permissible bed shear stress and velocity, with the hydraulic variables modelled as part of the flood study. This assessment found that the overall risk of rapid and significant geomorphic change in Tooloombah and Deep creeks and Styx River due to the proposed mining activity was negligible to low.

Geomorphic monitoring should include topographic survey of target areas, identified by this study as being at higher risk of geomorphic instability. Surveys should be repeated every year for 3 years, and then either every five years, or after every flood event exceeding the 5 yr ARI event. A Before-After, Control-Intervention monitoring design should be used, with tolerable limits of change in the intervention reaches set by the observed degree of change in control reaches.

Mitigation measures would be triggered by unexpectedly large geomorphic change identified through monitoring. The most appropriate response would need to be assessed at the time.

7.0 References

Abernethy, B. and Rutherfurd, I.D. 2000. The effect of riparian tree roots on the mass-stability of riverbanks. Earth Surf. Process. Landforms 25: 921-937.

Anon. 1936. The maximum permissible velocity in open channels. Gidrotekhnicheskoie Stroitel’stvo (Hydrotechnical Construction), Moscow, May, No. 5: 5-7.

Armston, J.D., Denham, R.J., Danaher, T.J., Scarth, P.F. and Moffiet, T.N. 2009. Prediction and Validation of Foliage Projective Cover from Landsat-5 TM and Landsat-7 ETM+ Imagery. Journal of Applied Remote Sensing 3: 033540, doi:10.1117/1.3216031.

Barka, I Vladovič, J and Máliš, F. 2011. Landform classification and its application in predictive mapping of soil

Bartley, R., Waters, D., Turner, R., Kroon, F., Wilkinson, S., Garzon-Garcia, A., Kuhnert, P., Lewis, S.,

Smith, R., Bainbridge, Z., Olley, J., Brooks, A., Burton, J., Brodie, J., Waterhouse, J. 2017. Scientific Consensus Statement 2017: A synthesis of the science of land-based water quality impacts on the Great Barrier Reef, Chapter 2: Sources of sediment, nutrients, pesticides and other pollutants to the Great Barrier Reef. State of Queensland. URL: https://www.reefplan.qld.gov.au/__data/assets/pdf_file/0031/45994/2017-scientific-consensus-statement-summary-chap02.pdf (accessed 1 July 2020).

Benn, S. 2015. Quantifying sediment transport from eroding gullies using LiDAR, BEnviSci Adv Hon, School of Earth & Environmental Sciences, University of Wollongong. URL: https://ro.uow.edu.au/cgi/viewcontent.cgi?article=1106&context=thsci (accessed 1 May 2020).

Blackham, D. 2006. The relationship between flow and stream channel vegetation. Unpublished PhD thesis. The School of Anthropology, Geography & Environmental Studies (SAGES), The University of Melbourne, Parkville.

Bond, N.R., Lake, P.S. an Arthington, A.H. 2008. The impacts of drought on freshwater ecosystems: an Australian perspective. Hydrobiologia 600: 3-16.

Bos, M.G. 1994. Drainage canals and related structures. Chapter 19 in Ritzema, H.P. (Ed.) 1994. Drainage Principles and Applications. ILRI Publication 16, Second Edition. International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands, pp. 725-798.

Brendryen, J., Haflidason, H., Yokoyama, Y., Agasøster Haaga, K. Hannisdal, B. 2020. Eurasian Ice Sheet collapse was a major source of Meltwater Pulse 1A 14,600 years ago. Nature Geoscience 20 April; doi:org/10.1038/s41561-020-0567-4.

Brierley, G.J. and Fryirs, K.A. 2000. River Styles, a geomorphic approach to catchment characterisation: Implications for river rehabilitation in Bega Catchment, NSW, Australia. Environmental Management 25(6): 661–679.

Brierley, G.J. and Fryirs, K.A. 2002. The River Styles® Framework: the Short Course Conceptual Book. Book given to participants in the course. Macquarie University, North Ryde.

Brierley, G.J. and Fryirs, K.A. 2005. Geomorphology and River Management: Applications of the River Styles® Framework. Blackwell Publishing, Cornwall.

Brierley, G.J. and Fryirs, K.A. 2006. The River Styles® Framework. http://www.riverstyles.com/ (accessed 1 July 2011).

Brierley, G.J. and Fryirs, K.A., Cook, N., Outhet, D., Raine, A., Parsons, L. and Healey, M. 2011. Geomorphology in action: Linking policy with on-the-ground actions through applications of the River Styles framework. Applied Geography 31: 1132-1143.

Brierley, G.J. and Wheaton, J. 2013. The River Styles framework: Three Day Professional Shortcourse, School of Environment, The University of Auckland, 8-10 October. URL: http://etal.usu.edu/Workshops/RiverStyles/2013/RS 2 Stage 1 (Character and Behaviour).pdf

Brierley, G.J., Fryirs, K.A., Outhet, D. and Massey, C. 2002. Application of the River Styles framework as a basis for river management in New South Wales, Australia. Applied Geography 22: 91-122.

Brooks, A., Spencer, J. and Knight, J. 2007. Alluvial gully erosion in Australia’s tropical rivers: a conceptual model as a basis for a remote sensing mapping procedure. Proceedings of the 5th Australian Stream Management Conference, May, Albury. URL: https://rbms.com.au/event/asm/5asm/ (accessed 1/04/2020).

Brooks, A., Spencer, J., Olley, J., Pietsch, T., Borombovits, D., Curwen, G., Shellberg, J., Howley, C., Gleeson, A., Simon, A., Bankhead, N., Klimetz, D., Eslami-Endargoli, L. and Bourgeault, A. 2013, An empirically-based sediment budget for the Normanby basin. Australian Rivers Institute, Griffith University.

Brooks, A.P., Shellberg, J.G., Knight, J., and Spencer, J. 2009. Alluvial gully erosion: an example from the Mitchell fluvial megafan, Queensland, Australia. Earth Surface Processes and Landforms 34(14): 1951-1969.

Brooks, A.P., Spencer, J., Olley, J., Pietsch, T., Borombovits, D., Curwen, G., Shellberg, J., Howley, C., Gleeson, A., Simon, A., Bankhead, N., Klimetz, D., Eslami-Endargoli, L. and Bourgeault, A. 2013. An Empirically-based Sediment Budget for the Normanby Basin: Sediment Sources, Sinks, and Drivers on the Cape York Savannah. Australian Rivers Institute, Griffith University, 506pp.

Carr, A.S., Bateman, M.D., Roberts, D.L., Murray-Wallace, C.V., Jacobs, Z. and Holmes, P.J. 2010. The last interglacial sea-level high stand on the southern Cape coastline of South Africa. Quaternary Research 73(2): 351-363.

Carter, A.C. 1953. Critical tractive forces on channel side slopes. U.S. Bureau of Reclamation, Hydraulic Laboratory Report No. Hyd-366 (supersedes Hyd-295), February.

CDM Smith 2017. Central Queensland Coal Project, Environmental Impact Statement. Central Queensland Coal, October.

CDM Smith 2018a. Central Queensland Coal Project, Supplementary Environmental Impact Statement. Central Queensland Coal, December.

CDM Smith 2018b. Chapter 5 Land, Central Queensland Coal Project, Supplementary Environmental Impact Statement. Central Queensland Coal, December.

CDM Smith 2018c. Chapter 9 Surface Water, Central Queensland Coal Project, Supplementary Environmental Impact Statement. Central Queensland Coal, December.

CDM Smith 2018d. Chapter 8 Waste Rock and Rejects, Central Queensland Coal Project, Supplementary Environmental Impact Statement. Central Queensland Coal, December.

Chang, H.H. 1988. Fluvial Processes in River Engineering, John Wiley and Sons, New York.

Chow, V.T. 1981. Open-Channel Hydraulics. McGraw Hill International Book Company. Tokyo, Japan.

Cohen, T.J. and Nanson, G.C. 2007. Mind the gap: An absence of valley-fill deposits identifying the Holocene hypsithermal period of enhanced flow regime in southeastern Australia. Holocene 17: 411–418

Cohen, T.J. and Nanson, G.C. 2008. Topographically associated but chronologically disjunct late Quaternary floodplains and terraces in a partly confined valley, south-eastern Australia. Earth Surface Processes and Landforms 33(3): 424-443.

Cook, N. and Schneider, G. 2006. River Styles® in the Hunter catchment. NSW Government, Department of Natural Resources.

CQC 2020. Central Qld Coal Project Supplementary Impact Assessment Version 3. Central Qld Coal.

Croke, J., Jansen, J.D., Amos, K., and Peitsch, T.J. 2011. A 100 ka record of fluvial activity in the Fitzroy River Basin, tropical northeastern Australia. Quaternary Science Reviews 30: 1681-1695.

Daley, J.S. and Cohen, T.J. 2018. Climatically-Controlled River Terraces in Eastern Australia. Quaternary 2018, 1, 23; doi:10.3390/quat1030023.

Davies-Colley, R. 1997. Stream channels are narrower in pasture than in forest, New Zealand Journal of Marine and Freshwater Research 31: 599-608.

Department of Agriculture, Water and the Environment 2018. Reef 2050 Plan. Australian Government. URL: http://www.environment.gov.au/marine/gbr/long-term-sustainability-plan (accessed 9/07/2020).

Department of Natural Resources and Mines 2014. Guideline: Works that interfere with water in a watercourse—watercourse diversions. State of Queensland, September.

Department of Natural Resources, Mines and Energy 2019. Queensland Spatial Catalogue, QSpatial. The State of Queensland, Department of Natural Resources, Mines and Energy, Qeensland Government. URL: https://qldspatial.information.qld.gov.au (accessed 1/04/2020).

DERM 2011. Department of Environment and Resource Management, Watercourse Diversions – Central Queensland Mining Industry, Central West Region, Queensland.

Dougherty, A.J., Thomas, Z.A., Fogwill, C., Hogg, A., Palmer, J., Rainsley, E., Wiliams, A.N., Ulm, S., Rogers, K., Jones, B.G. and Turney, C. 2019. Redating the earliest evidence of the mid-Holocene relative sea-level highstand in Australia and implications for global sea-level rise. PLoS ONE 14(7): e0218430; doi:org/10.1371/journal.pone.0218430.

Engeny Water Management 2020a. Conceptual Erosion and Sediment Control Plan, Central Queensland Coal Project. Central Queensland Coal, March.

Engeny Water Management 2020b. Project Sediment Budget Assessment, Central Queensland Coal Project. Central Queensland Coal, June.

Fischenich, C.J. 2001. Stability Thresholds for Stream Restoration Materials. EMRRP Technical Notes Collection (ERDC TNEMRRP-SR-29), U.S. Army Engineer Research and Development Center, Vicksburg, MS.URL: https://www.marincounty.org/depts/cu/~/media/files/departments/pw/mcstoppp/residents/fischenichstabilitythresholds.pdf (accessed 17 April 2018).

Fischenich, C.J. and Allen, H. 2000. Stream management. Water Operations Technical Support Program Special Report ERDC/EL SRW-00-1, Vicksburg, MS. URL: https://www.engr.colostate.edu/~pierre/ce_old/classes/ce717/Manuals/Fischenich/Fischenich%20Allen%202000.pdf (accessed 17 April 2018).

Fortier, S. and Scobey, F.C. 1926. Permissible canal velocities. Transactions, American Society of Civil Engineers 89: 940-956.

Frissell, C. A.; Liss, W. J.; Warren, C. E.; Hurley, M. D. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10(2): 199-214.

Fryirs, K.A. 2003. Guiding principles of assessing the geomorphic condition of rivers: application of a framework in Bega catchment, South Coast, NSW, Australia. Catena 53:17-52.

Fryirs, K.A. and Brierley, G.J. 2005. Practical application of the River Styles® framework as a tool for catchment-wide river management: a case study from Bega catchment, New South Wales. Macquarie University. URL: http://www.riverstyles.com/ebook.php (accessed 15 Jan 2015).

Fryirs, K.A. and Brierley, G.J. 2006. Linking geomorphic character, behaviour and condition to fluvial biodiversity: implications for river management. Aquatic Conservation: Marine and Freshwater Ecosystems 16: 267–288.

Fryirs, K.A. and Brierley, G.J. 2010. Antecedent controls on river character and behaviour in partly-confined valley settings: upper Hunter catchment, NSW, Australia. Geomorphology 117: 106-120.

GHD 2014. NDRP Storm Tide Hazard Interpolation Study. Department of Environment and Science, Brisbane, June.

Gill, T., Johansen, K., Phinn, S., Trevithick, R., Scarth, P. and Armston, J. 2017. A method for mapping Australian woody vegetation cover by linking continental-scale field data and long-term Landsat time series, International Journal of Remote Sensing 38(3): 679-705.

Gippel, C.J. 1995. Environmental hydraulics of large woody debris in streams and rivers. Journal of Environmental Engineering 121: 388-395.

Gippel, C.J., Finlayson, B.L. and O'Neill, I.C. 1996. Distribution and hydraulic significance of large woody debris in a lowland Australian River. Hydrobiologia 318(3): 179-194.

Gordon, N.D., McMahon, T.A., Finlayson, B.L., Gippel, C.J. and Nathan, R.J. 2004. Stream Hydrology: An Introduction for Ecologists. Second Edition, John Wiley & Sons, Chichester.

Gornitz, V. 2007. Sea Level Rise, After the Ice Melted and Today. Science Briefs. Goddard Institute for Space Studies, National Aeronautics and Space Administration (NASA), Sciences and Exploration Directorate, Earth Sciences Division. URL: https://www.giss.nasa.gov/research/briefs/gornitz_09/ (accessed 1 April 2020).

Hails, J.R., Belperio, A.P. and Gostin, V.A. 1984. Quaternary sea levels, northern Spencer Gulf, Australia. Marine Geology 61(2-4): 373-389.

Hardie, R and Lucas, R. 2002. Bowen Basin River Diversions Design and Rehabilitation Criteria. Project C9068 Report for Australian Coal Association Research Program (ACARP). Fisher Stewart Ltd, July.

Hearty, P.J., Hollin, J.T., Neumann, A.C., O'Leary, M.J. and McCulloch, M. 2007. Global sea-level fluctuations during the Last Interglaciation (MIS 5e). Quaternary Science Reviews 26: 2090–2112.

Hession, W.C., McBride, M. and Pizzuto, J.E. 2008. Riparian vegetation influence on channel morphology. AWRA Summer Specialty Conference, Riparian Ecosystems and Buffers: Working at the Water's Edge, Virginia Beach, VA.

HESSE 2020. Agricultural Land and Soil Suitability CQC Project. Horizon Environmental Soil Survey & Evaluation, Nakara NT. Central Queensland Coal.

Huang, H.Q. and Nanson, G.C. 1997. Vegetation and channel variation; a case study of four small streams in southeastern Australia. Geomorphology, 18: 237-249.

Hudson, N. 1971. Soil Conservation, Cornell University Press, Ithaca.

Hughes, K. and Croke, J. 2017. How did rivers in the wet tropics (NE Queensland, Australia) respond to climate changes over the past 30 000 years? Journal of Quaternary Science 32(6): 744-759.

Isbell, R.F. 2002. The Australian Soil Classification. Revised Edition. CSIRO Publishing, Melbourne.

Jenson, S.K. and Domingue, J.O. 1988. Extracting topographic structure from digital elevation model data for geographic information system analysis, Photogramm. Eng. Rem. S. 54(11): 1593–1600.

Kopp, R.E., Simons, F.J., Mitrovica, J.X., Maloof, A.C. and Oppenheimer, M. 2009. Probabilistic assessment of sea level during the last interglacial stage. Nature 462: 863–867.

Lambeck, K. and Nakada, M. 1990. Late Pleistocene and Holocene sea-level change along the Australian coast. Palaeogeography, Palaeoclimatology, Palaeoecology 89(1-2): 143-176.

Lane, E.W. 1952. Progress report on results of studies on design of stable channels. U.S. Bureau of Reclamation, Hydraulic Laboratory Report No. Hyd-352, June. URL: https://www.usbr.gov/tsc/techreferences/hydraulics_lab/pubs/HYD/HYD-352.pdf (accessed 17 April 2018).

Lane, E.W. 1955. Design of stable channels. Transactions, American Society of Civil Engineers 120: 1234-1260.

Leonard, S. and J. Nott 2015. Rapid Cycles of Episodic Adjustment: Understanding the Holocene fluvial archive of the Daintree River of Northeastern Australia. The Holocene 25(8): 1208-1219.

Lewis, S.E., Sloss, C.R., Murray-Wallace, C.V., Woodroffe, C.D. and Smithers, S.G. 2013. Post-glacial sea-level changes around the Australian margin: a review. Quaternary Science Reviews. 74: 115-138.

Lewis, S.E., Wüst, R.A.J., Webster, J.M. and Shields, G.A. 2008. Mid ‐ late Holocene sea ‐ level variability in eastern Australia. Terra Nova 20(1): 74-81; doi:org/10.1111/j.1365-3121.2007.00789.x.

Ludt, W.B and Rocha, L.A. 2014. Shifting seas: the impacts of Pleistocene sea ‐ level fluctuations on the evolution of tropical marine taxa. J. Biogeography 42(1): 25-38.

Montgomery, D,R. 1997. What's best on the banks? Nature 388: 328-329.

Munné, A., Prat, N., Solà, C, Bonada, N. and Rieradevall, M. 2003. A simple field method for assessing the ecological quality of riparian habitat in rivers and streams: QBR index. Aquatic Conserv: Mar. Freshw. Ecosyst. 13: 147–163.

Murray-Wallace, C.V. 2002. Pleistocene coastal stratigraphy, sea-level highstands and neotectonism of the southern Australian passive continental margin - a review. Journal of Quaternary Science 17: 469-489.

Murray-Wallace, C.V. and Belperio, A.P. 1991. The last interglacial shoreline in Australia: a review. Quaternary Science Reviews 10: 441-461.

Murray-Wallace, C.V., Belperio, A.P., Dosseto, A., Nicholas, W.A., Mitchell, C., Bourman, R.P., Eggins, S.M. and Grun, R. 2016. Lastinterglacial (MIS 5e) sea-level determined from a tectonically stable, far-field location, Eyre Peninsula, southern Australia. Australian Journal of Earth Sciences 63 (5): 611-630.

O'Leary, M.J., Hearty, P.J. and McCulloch, M.T. 2008. Geomorphic evidence of major sea-level fluctuations during marine isotope substage-5e, Cape Cuvier, Western Australia. Geomorphology 102: 595-602.

Outhet, D. and Cook, N. 2004. Definitions of geomorphic condition categories for streams. Unpublished internal draft paper for use throughout NSW by the Department of Infrastructure, Planning and Natural Resources.

Outhet, D. and Young, C. 2004a. Using reference reaches to suggest causes of poor river geomorphic condition. In Rutherfurd, I. (ed.), Proceedings 4th Australian Stream Management Conference, Launceston, Tasmania, 20-22 Oct., pp. 470-476.

Outhet, D. and Young, C. 2004b. River Style Geomorphic Fragility. Unpublished internal draft paper for use throughout NSW by the Department of Infrastructure, Planning and Natural Resources.

Pietsch, T.J., Brooks, A.P., Spencer, J., Olley, J.M., Borombovits, D. 2015. Age, distribution, and significance within a sediment budget, of in-channel depositional surfaces in the Normanby River, Queensland, Australia, Geomorphology 239: 17-40; doi: 10.1016/j.geomorph.2015.01.03

Prosser, I.P. 2018. Improving how gully erosion and river sediment transport processes are represented in Queensland catchment models. Report to Queensland Water Modelling Network, Department of Environment and Science.

Prosser, I.P. and Slade, C.J. 1994. Gully formation and the role of valley-floor vegetation, southeastern Australia. Geology 22: 1127-1130.

Prosser, I.P., Dietrich, W.E. and Stevenson, J. 1995. Flow resistance and sediment transport by concentrated overland flow in a grassland valley. Geomorphology 13: 71-86.

Raven, P.J., Holmes, N.T.H., Dawson F.H. and Everard, M. 1998. Quality assessment using River Habitat Survey data. Aquatic Conserv: Mar. Freshw. Ecosyst. 8: 477-499.

Reid, L.M. 1989. Erosion of Grassed Hillslopes, University of Washington, Washington.

RGS Environmental 2020. Land Stability Assessment. Central Queensland Coal Project. Central Queensland Coal Pty Ltd, May.

Shellberg, J., Brooks, A. and Spencer, J. 2010. Land-use change from indigenous management to cattle grazing initiates the gullying of alluvial soils in northern Australia. Soil Solutions for a Changing World, 19th World Congress of Soil Science, 1 - 6 August 2010. Brisbane, Australia, pp. 59-62.

Shellberg, J.G. 2011. Alluvial Gully Erosion Rates and Processes Across the Mitchell River Fluvial Megafan in Northern Queensland, Australia. PhD thesis, Griffith School of Environment Science, Environment, Engineering and Technology, Griffith University, November.

Shellberg, J.G., Brooks, A.P. and Rose, C.W. 2013. Sediment production and yield from an alluvial gully in northern Queensland, Australia. Earth Surface Processes and Landforms 38(15): 1765-1778; doi: 10.1002/esp.3414.

Sloss, C.R., Nothdurft, L., Hua, Q., O'Connor, S.G., Moss, P.T., Rosendahl, D., Petherick, L.M., Nanson, R.A., Mackenzie, L.L., Sternes, A., Jacobsen, G.E., and Ulm, S. 2018. Holocene sea-level change and coastal landscape evolution in the southern Gulf of Carpentaria, Australia. Holocene 28(9): 1411-1430.

Speight, J.G. 2009. Landform. In Australian Soil and Land Survey Field Handbook, Third Edition. The National Committee on Soil and Terrain. CSIRO Publishing, Collingwood, pp. 15 – 72.

Sprague, C.J. 1999. Green engineering: Design Principles and applications using rolled erosion control products. CE News, March, pp. 76-81.

Spratt, R.M. and Lisiecki, L.E. 2016. A Late Pleistocene sea level stack. Climate of the Past 12: 1079-1092; doi:10.5194/cp-12-1079-2016.

Stallings, S.L. 1999. Roadside ditch design and erosion control on Virginia Highways. Masters of Science in Civil Engineering Thesis (unpublished), Faculty of the Virginia Polytechnic Institute and State University, Blacksburg, Virginia, September. URL: https://vtechworks.lib.vt.edu/bitstream/handle/10919/35094/sheila.pdf;sequence=1 (accessed 17 April 2018).

SunWater 2015. Lower Fitzroy River Infrastructre Project, Draft environmental impact statement June 2015, Appendix P2, Surface water resources supporting material, Part 2 Section 3 Existing environment (stream flow hydrology and flooding), Part 2 Section 4 Potential impacts on stream flow patterns.

Sweeney, B.W. 1993. Effects of streamside vegetation on macroinvertebrate communities of White Clay Creek in eastern North-America, Proceedings of the Academy of Natural Sciences of Philadelphia 144: 291-340.

Tindall, D., Marchand, B., Gilad, U., Goodwin, N., Denham, R. and Byer, S. 2014, Gully mapping and drivers in the grazing lands of the Burdekin catchment. RP66G Synthesis Report. Queensland Department of Science, Information Technology, Innovation and the Arts, Brisbane.

Tomazelli, L.J. and Dillenburg, S.R. 2007. Sedimentary facies and stratigraphy of a last interglacial coastal barrier in south Brazil. Marine Geology 244: 33-45.

Trevithick, R., Herring, M., Dougall, C. and Pringle, M. 2010. Gully length density mapping and modelling for the Fitzroy Basin, Queensland, Australia. Department of Environment and Resource Management, State of Queensland.

Trimble, S.W. 1997. Stream channel erosion and change resulting from riparian forests, Geology, 25: 467-469.

Ulm, S., Williams, A.N., Turney, C. and Lewis, S. 2018. Australia’s coastal living is at risk from sea level rise, but it’s happened before. The Conversation Friday 19 January. URL: https://theconversation.com/australias-coastal-living-is-at-risk-from-sea-level-rise-but-its-happened-before-87686 (accessed 1/04/2020).

Vekta 2011. Styx Coal Mine Project Report. Yeats Consulting Engineers, Vekta Pty Ltd, 13 September.

Vernon, C. 2008. Central West Water Management and Use Regional Guideline: Watercourse Diversions – Central Queensland Mining Industry (Version 4.0), Department of Environment and Resource Management, Queensland Government.

White, K., Hardie, R., Lucas, R., Merritt, J. and Kirsch, B. 2014. The evolution of watercourse diversion design in central; Queensland coal mines. In Vietz, G; Rutherfurd, I.D, and Hughes, R. (editors), Proceedings of the 7th Australian Stream Management Conference. Townsville, Queensland, Pages 238-248.

White, K., Hardie, R., Lucas, R., Merritt, J. and Kirsch, B. 2014. The evolution of watercourse diversion design in central Queensland coal mines. In Vietz, G; Rutherfurd, I.D, and Hughes, R. (eds), Proceedings of the 7th Australian Stream Management Conference. Townsville, Queensland, pp. 238-248.

Wilkinson, S. Brooks, A., Hairsine, P., Crawford, D., Bartley, R. and Pietsch, T. 2016. Gully and Stream Bank Toolbox. A technical guide for the Reef Trust Phase IV Gully and Stream Bank Erosion Control Program, Commonwealth of Australia.

Williams, A.N., Ulm, S., Sapienza, T., Lewis, S. and Turney, C.S.M. Sea-level change and demography during the last glacial termination and early Holocene across the Australian continent. Quaternary Science Reviews 182: 144-154.

Wilson, J.P. and Gallant, J.C. 1998. Terrain-based approaches to environmental resource evaluation. In: Lane, S., Richards, K., Chandler, J. (Eds.), Landform Monitoring, Modelling and Analysis. Wiley, Chichester, pp. 219–240.

Wilson, J.P. and Gallant, J.C. 2000. Terrain Analysis: Principles and Application. John Wiley & Sons, New York.

Wilson, P.R. and Taylor, P.M. 2012. Land Zones of Queensland. Queensland Herbarium, Queensland Department of Science, Information Technology, Innovation and the Arts, Brisbane. 79 pp. URL: https://www.qld.gov.au/environment/plants-animals/plants/ecosystems/descriptions/land-zones (accessed 1/04/2020).

Woodruff, D.S. 2010. Biogeography and conservation in Southeast Asia: how 2.7 million years of repeated environmental fluctuations affected today's patterns and the future of the remaining refugial - phase biodiversity. Biodiversity and Conservation 19: 919–941.

WRM Water & Environment 2020. Flood study and site water balance technical report, Central Queensland Coal Project. WRM Water & Environment Pty Ltd, Brisbane. Central Queensland Coal.

Zund, P.R. 2017. Fitzroy NRM Region Soil Erodibility. User guide. Department of Science, Information Technology, Innovation. Queensland Government, Brisbane. URL: https://www.publications.qld.gov.au/dataset/43052e44-e71e-42fb-83b2-587ec18005d5/resource/49612091-7495-45de-9ced-1811f375756a/fs_download/userguidev1fitzroysoilerodibilitydataset.pdf (accessed 1 May 2020).

ATTACHMENT 7
TARGETED GROUNDWATER INVESTIGATION RESULTS – AQUIFER TESTING (AMEC, 2019)

Table A7-1
AMEC (2019) Table 6 - Open End Permeability Test Results

Hole Number	Depth (m)	Description	Water Loss (L/s)	Permeability (m/s)
STX1901B	3.0	Clayey Sand	0.0000303	2.5 x 10^{-8}
STX1901C	18.0	Clay, Sand (Weathered Rock)	0.0000083	1.0 x 10^{-9}
STX1902B	6.0	Sandy Clay	0.0000833	3.7 x 10^{-8}
STX1902C	18.0	Clay (Weathered Rock)	0.0000044	1.3 x 10^{-8}

Source: AMEC (2019)

Table A7-2
AMEC (2019) Table 7 - Water Pressure Test Results, Drill Hole STX1901A

Depth Interval (m)	Water Loss (L/s)	Pressure (m Head)	Corrected Pressure (m Head)	Permeability (m/s)
31.0 – 112.0	0.483	56.0	54.5	1.29 x 10^{-7}
31.0 – 41.0	0.203	46.0	46.0	3.73 x 10^{-7}
40.0 – 112.0	0.067	46.0	46.0	2.30 x 10^{-8}
49.0 – 112.0	0.073	46.0	46.0	2.90 x 10^{-8}
58.0 – 112.0	0.070	46.0	46.0	3.10 x 10^{-8}
67.0 – 112.0	0.067	46.0	46.0	3.50 x 10^{-8}
76.0 – 112.0	0.047	46.0	46.0	3.00 x 10^{-8}
80.0 – 112.0	0.123	66.0	66.0	6.00 x 10^{-8}
90.0 – 112.0	0.103	66.0	66.0	6.90 x 10^{-8}

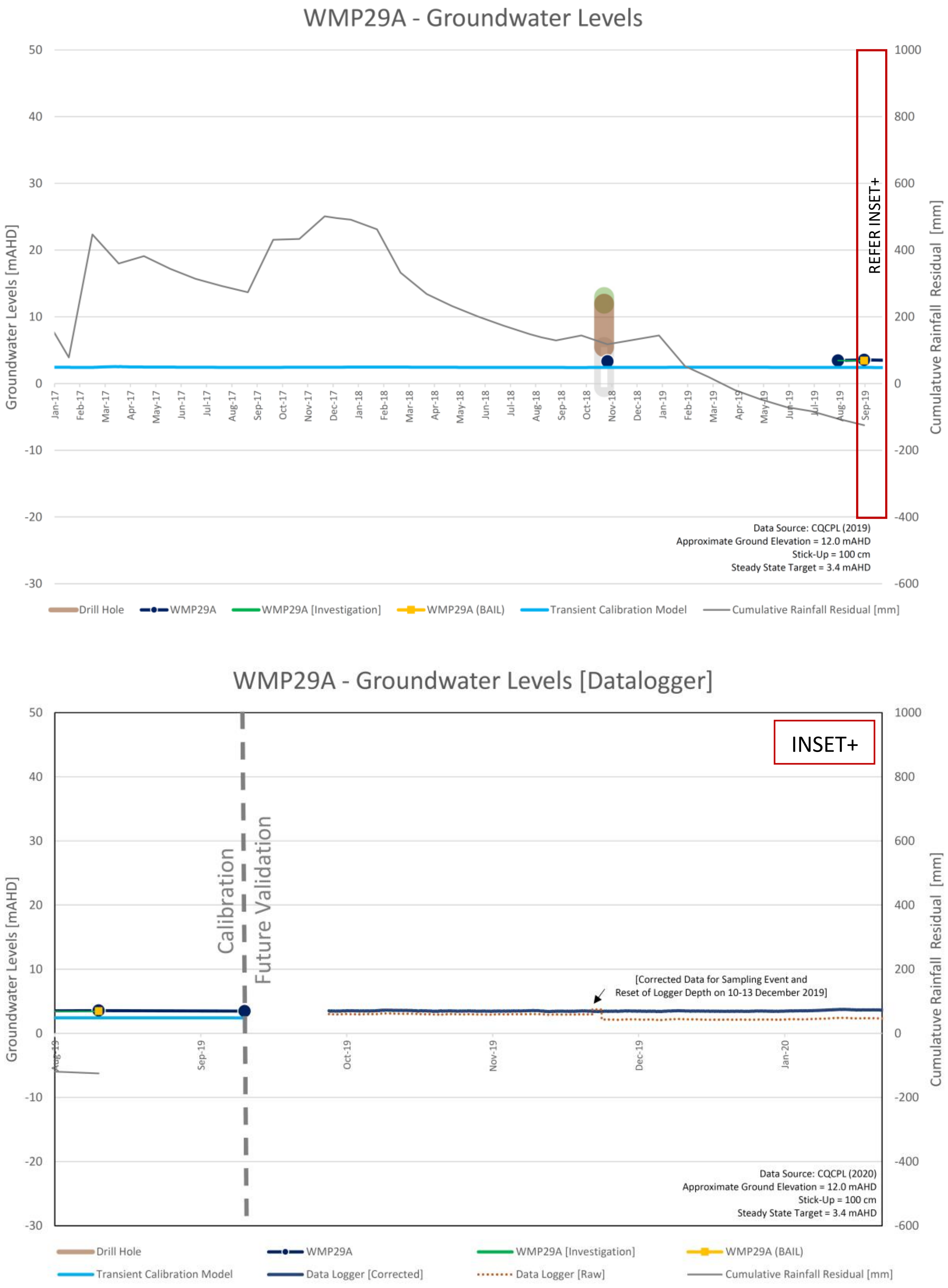
Source: AMEC (2019)

Table A7-3
AMEC (2019) Table 8 - Water Pressure Test Results, Drill Hole STX1902A

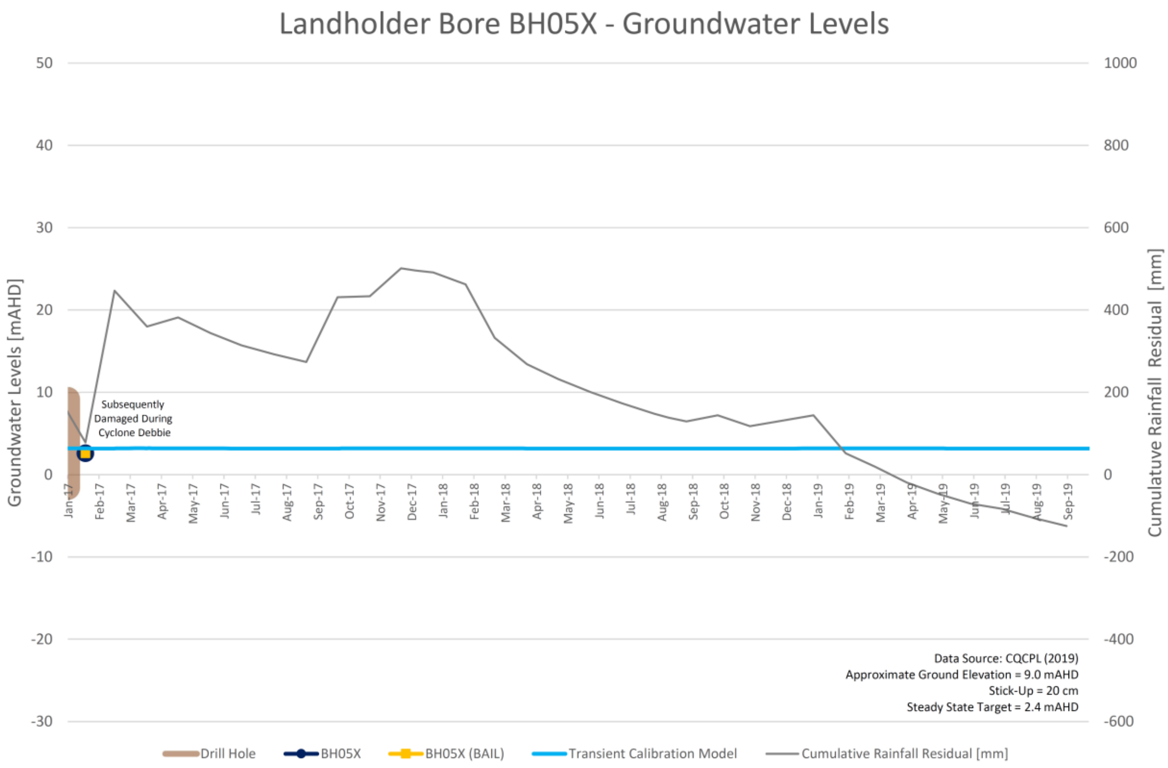
Depth Interval (m)	Water Loss (L/s)	Pressure (m Head)	Corrected Pressure (m Head)	Permeability (m/s)
25.0 – 170.0	0.147	42.2	42.2	3.00 x 10^{-8}
25.0 – 35.0	0.067	42.2	42.2	1.33 x 10^{-7}
34.0 – 44.0	0.043	42.2	42.2	8.70 x 10^{-8}
43.0 – 53.0	0.013	42.2	42.2	2.70 x 10^{-8}
52.0 – 62.0	0.010	42.2	42.2	2.00 x 10^{-8}
61.0 – 71.0	0.003	42.2	42.2	6.00 x 10^{-9}
70.0 – 80.0	0.010	42.2	42.2	2.00 x 10^{-8}
79.0 – 89.0	0.010	42.2	42.2	2.00 x 10^{-8}
88.0 – 98.0	0.017	42.2	42.2	3.30 x 10^{-8}
97.0 – 170.0	0.037	42.2	42.2	1.00 x 10^{-8}
133.0 – 170.0	0.020	42.2	42.2	1.10 x 10^{-8}

Source: AMEC (2019)

ATTACHMENT 8
GROUNDWATER DATASETS - HYDROGRAPHS

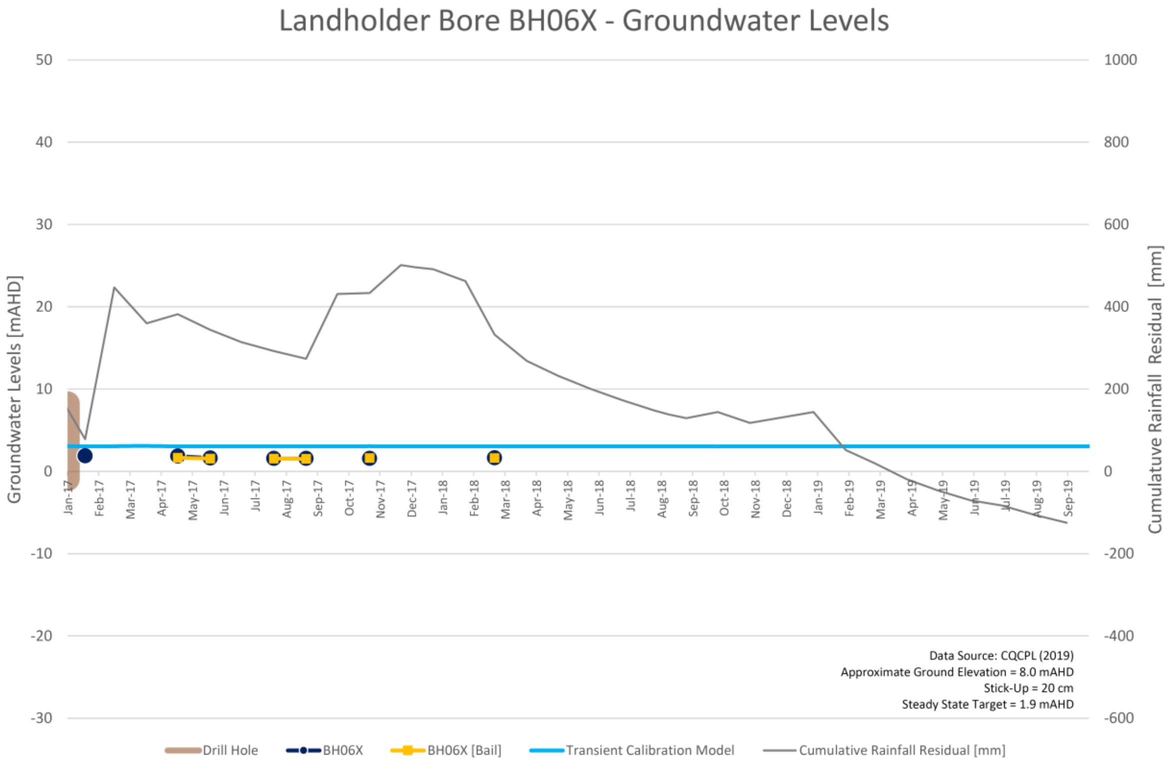


Graph A8-1: Cenozoic Deposits – Quaternary Holocene Estuarine Alluvium [WMP29A]



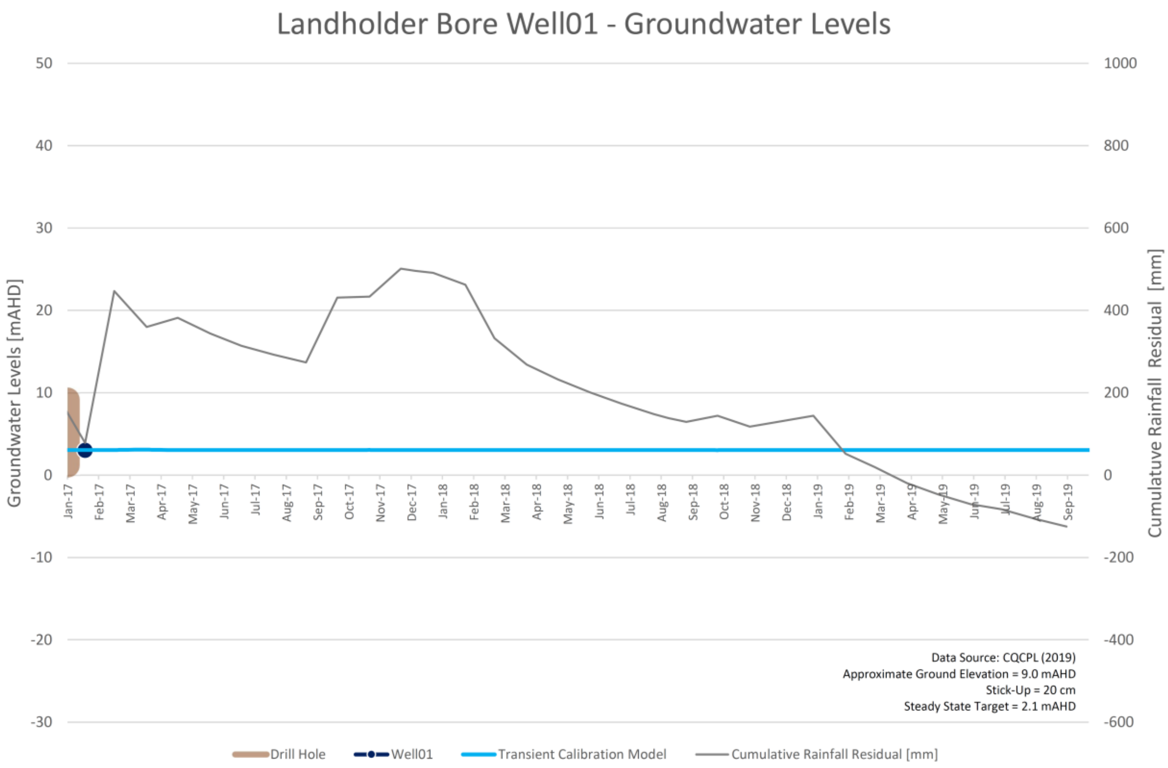
Data Source: CQCPL (2019)
Approximate Ground Elevation = 9.0 mAHD
Stick-Up = 20 cm
Steady State Target = 2.4 mAHD

Graph A8-2: Cenozoic Deposits – Quaternary Holocene Estuarine Alluvium [Landholder Bore – BH05X]

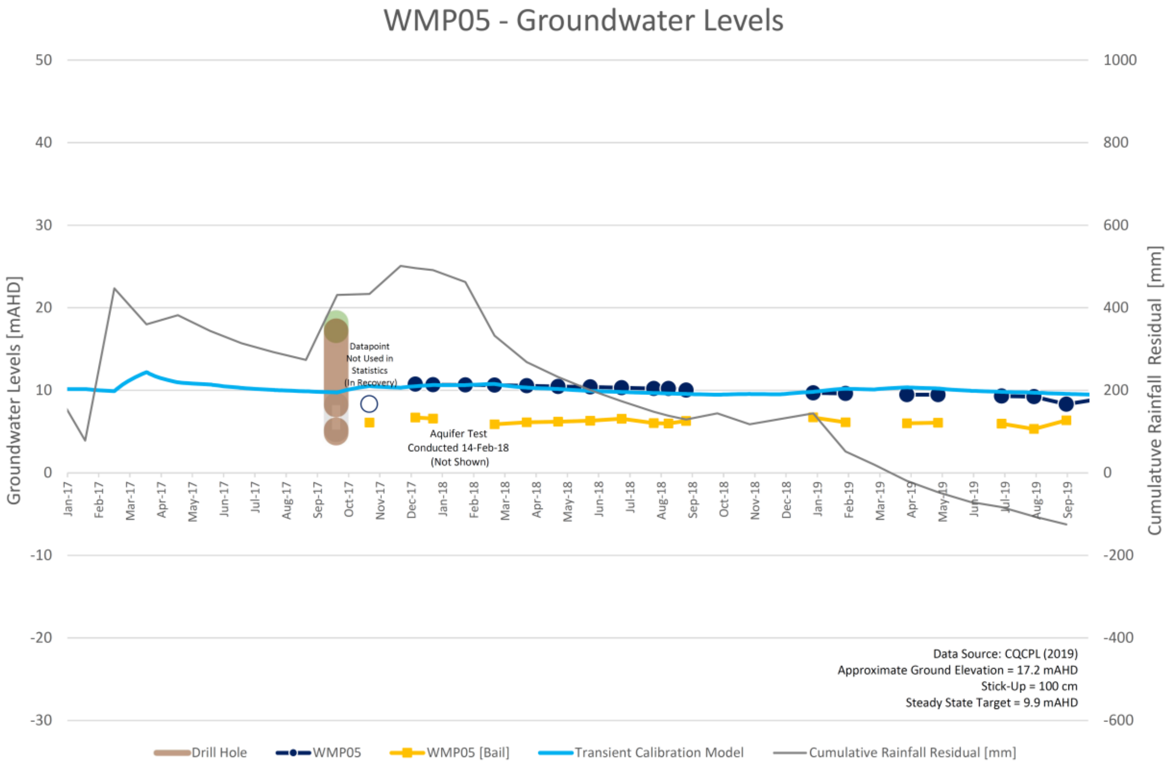


Data Source: CQCPL (2019)
Approximate Ground Elevation = 8.0 mAHD
Stick-Up = 20 cm
Steady State Target = 1.9 mAHD

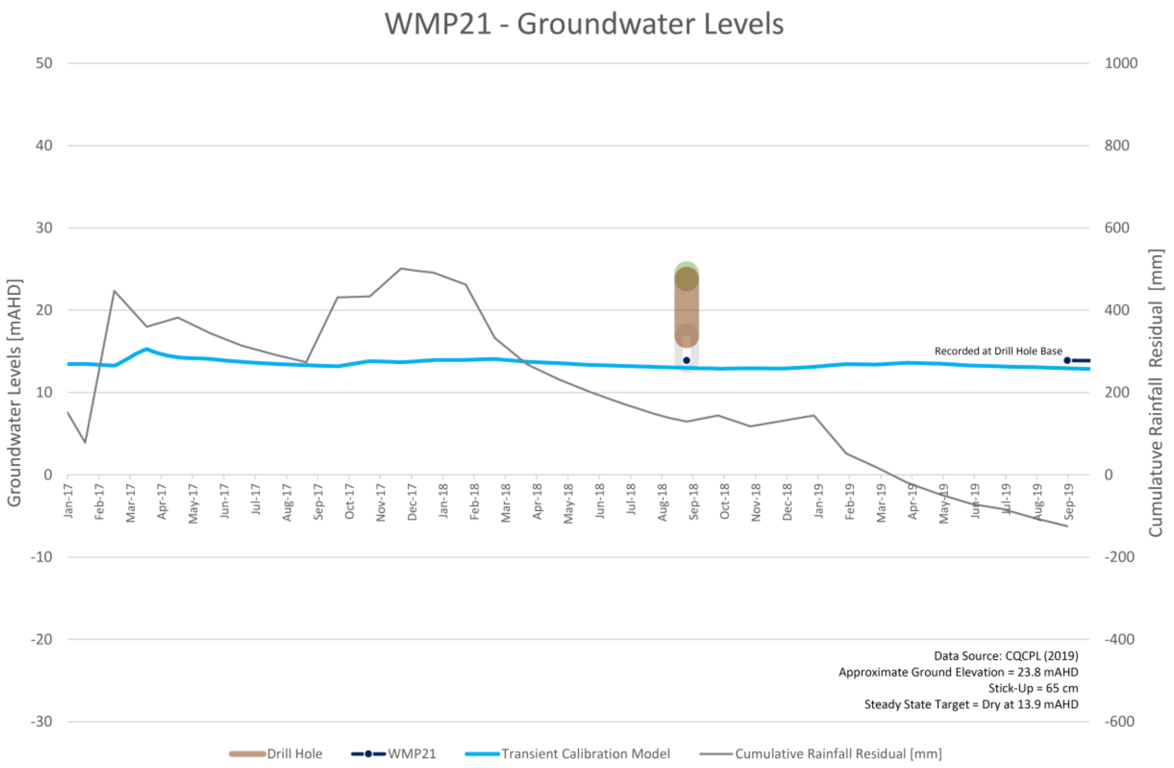
Graph A8-3: Cenozoic Deposits – Quaternary Holocene Estuarine Alluvium [Landholder Bore – BH06X]



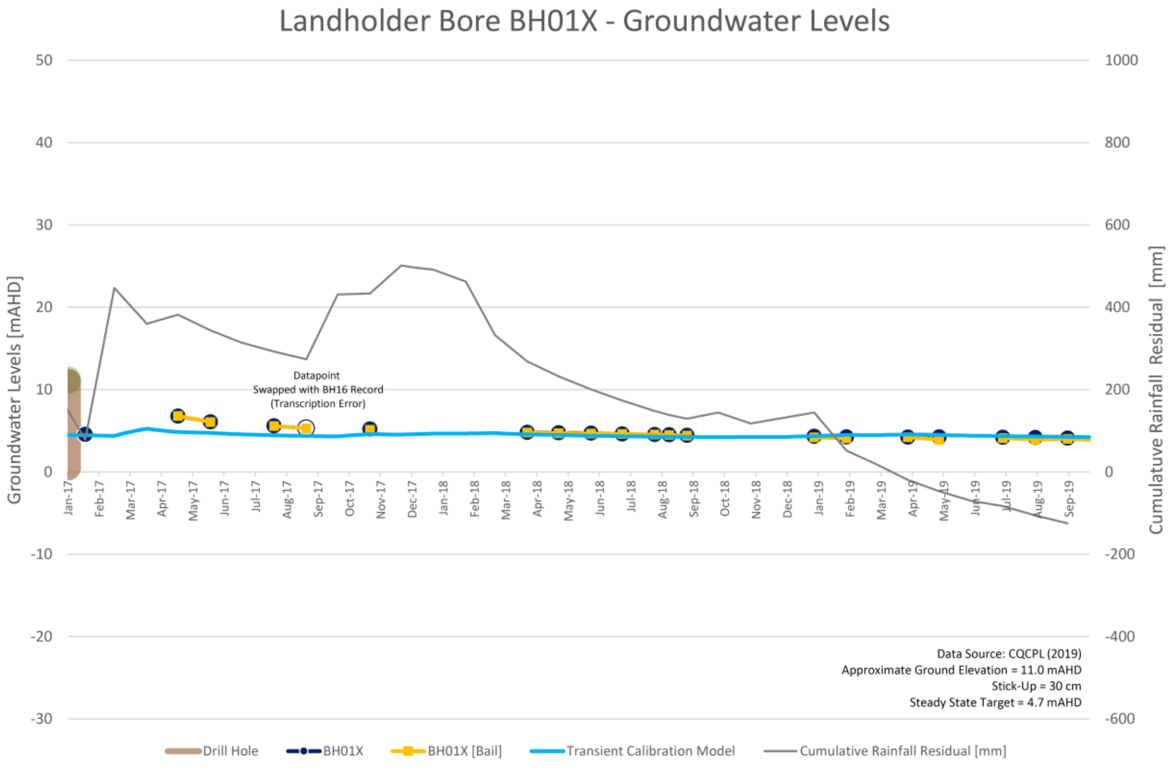
Graph A8-4: Cenozoic Deposits –
Quaternary Holocene Estuarine Alluvium
[Landholder Bore – Well01]



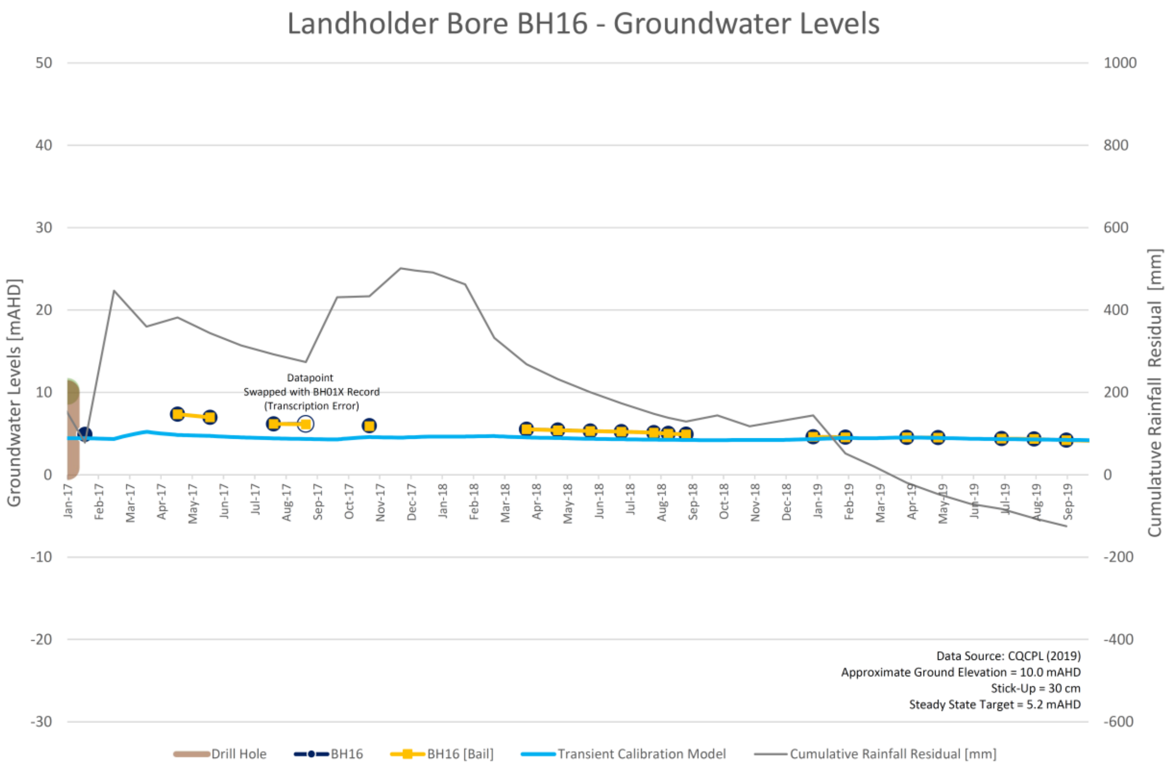
Graph A8-5: Cenozoic Deposits –
Quaternary Alluvium
[WMP05]



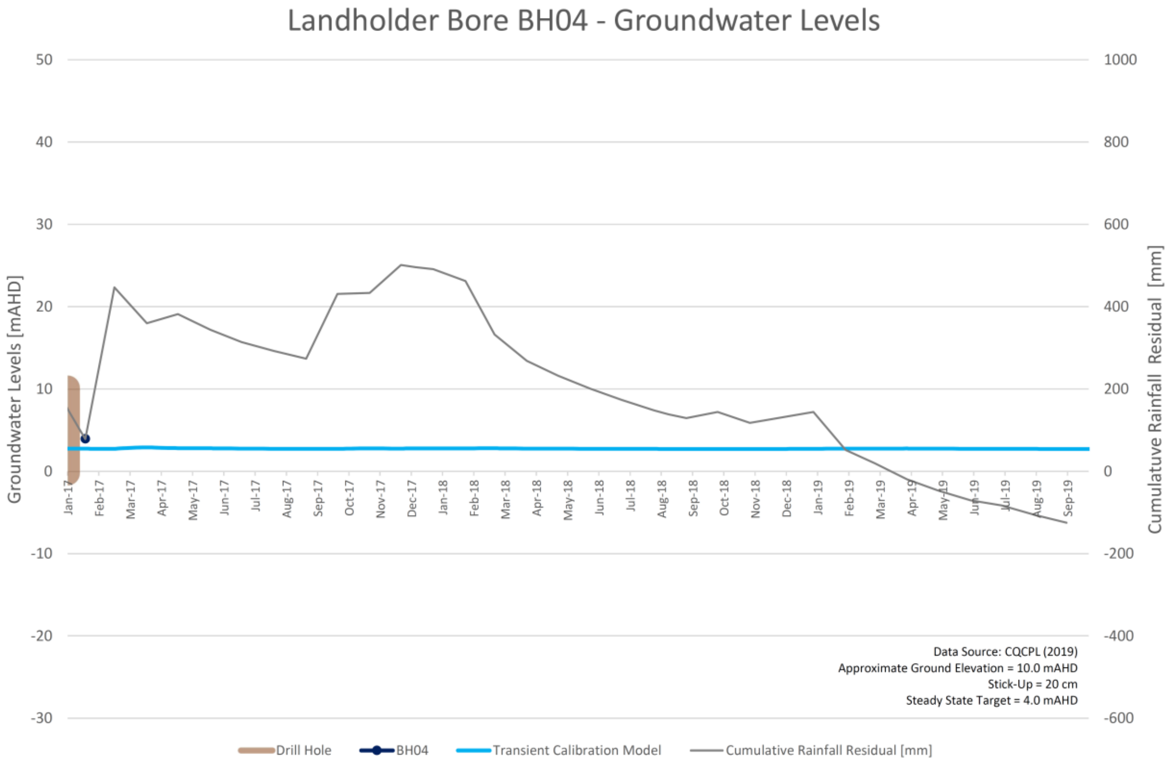
Graph A8-6: Cenozoic Deposits –
Quaternary Alluvium
[WMP21]



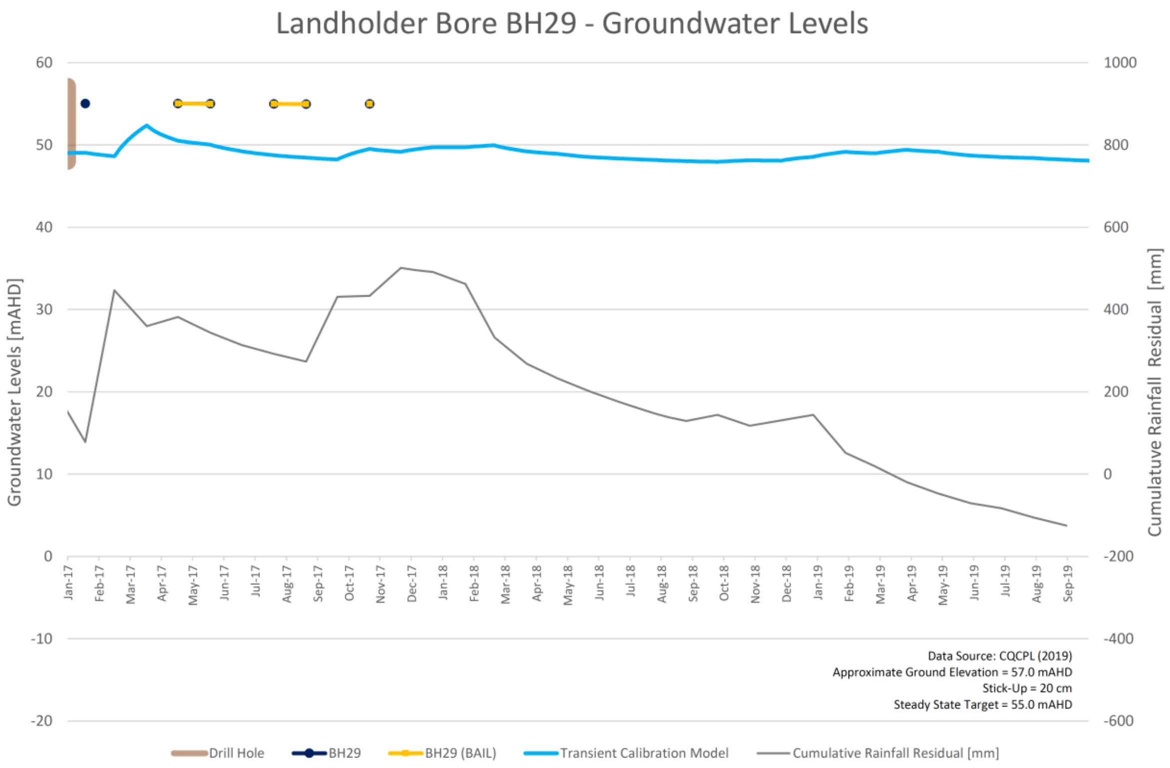
Graph A8-7: Cenozoic Deposits –
Quaternary Alluvium
[Landholder Bore – BH01X]



**Graph A8-8: Cenozoic Deposits –
Quaternary Alluvium
[Landholder Bore – BH16]**

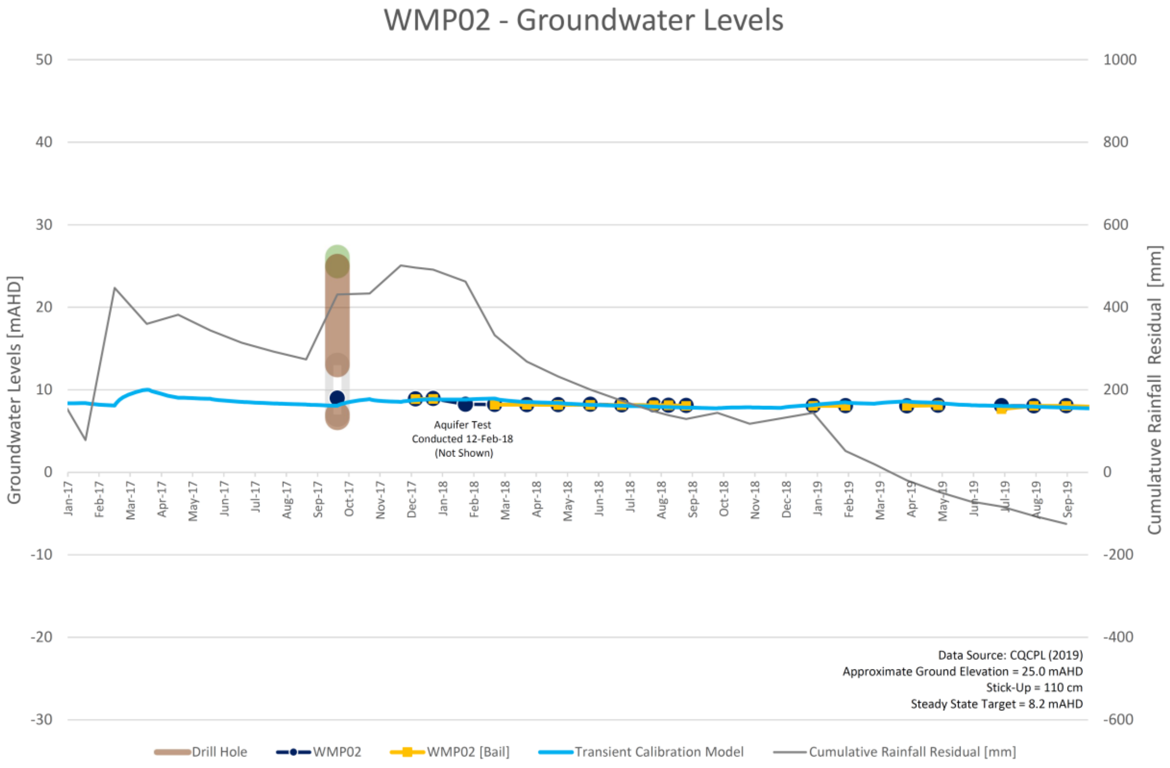


**Graph A8-9: Cenozoic Deposits –
Quaternary Alluvium
[Landholder Bore – BH04]**



Data Source: CQCPL (2019)
Approximate Ground Elevation = 57.0 mAHD
Stick-Up = 20 cm
Steady State Target = 55.0 mAHD

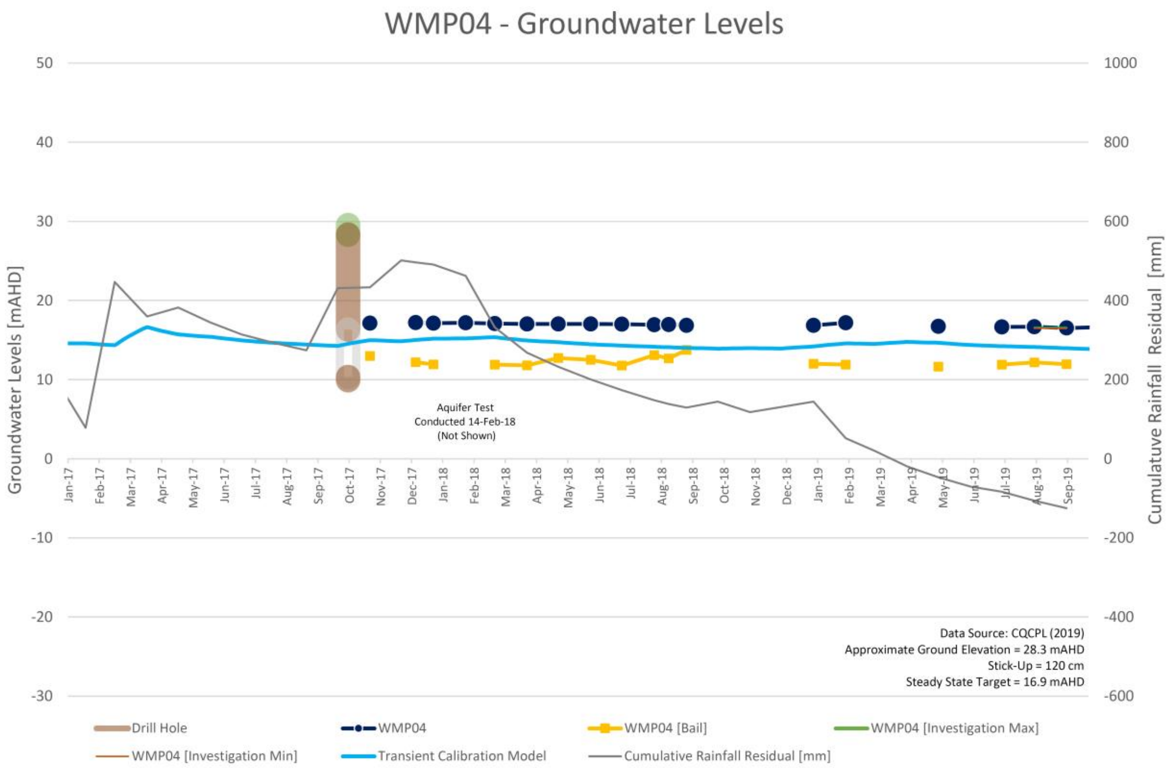
Graph A8-10: Cenozoic Deposits – Quaternary Alluvium [Landholder Bore – BH29]



Aquifer Test Conducted 12-Feb-18 (Not Shown)

Data Source: CQCPL (2019)
Approximate Ground Elevation = 25.0 mAHD
Stick-Up = 110 cm
Steady State Target = 8.2 mAHD

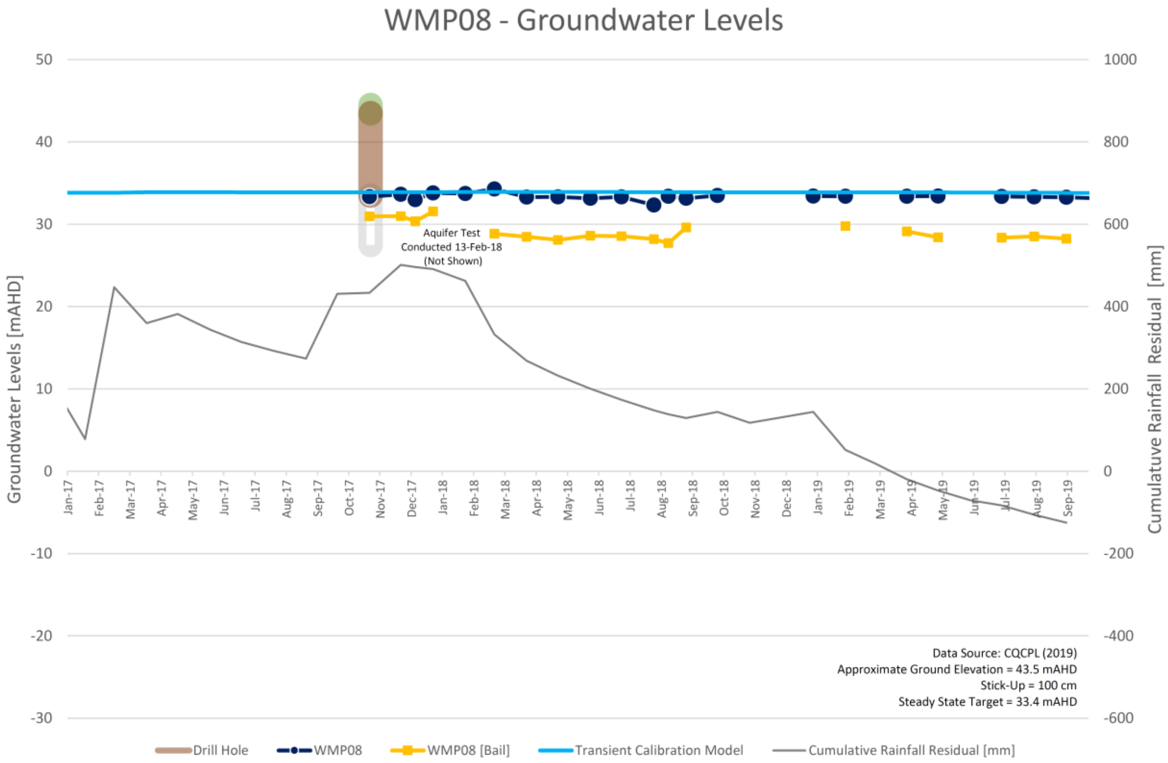
Graph A8-11: Cenozoic Deposits – Quaternary Pleistocene Alluvium / Regolith [WMP02]



Aquifer Test
Conducted 14-Feb-18
(Not Shown)

Data Source: CQCPL (2019)
Approximate Ground Elevation = 28.3 mAHD
Stick-Up = 120 cm
Steady State Target = 16.9 mAHD

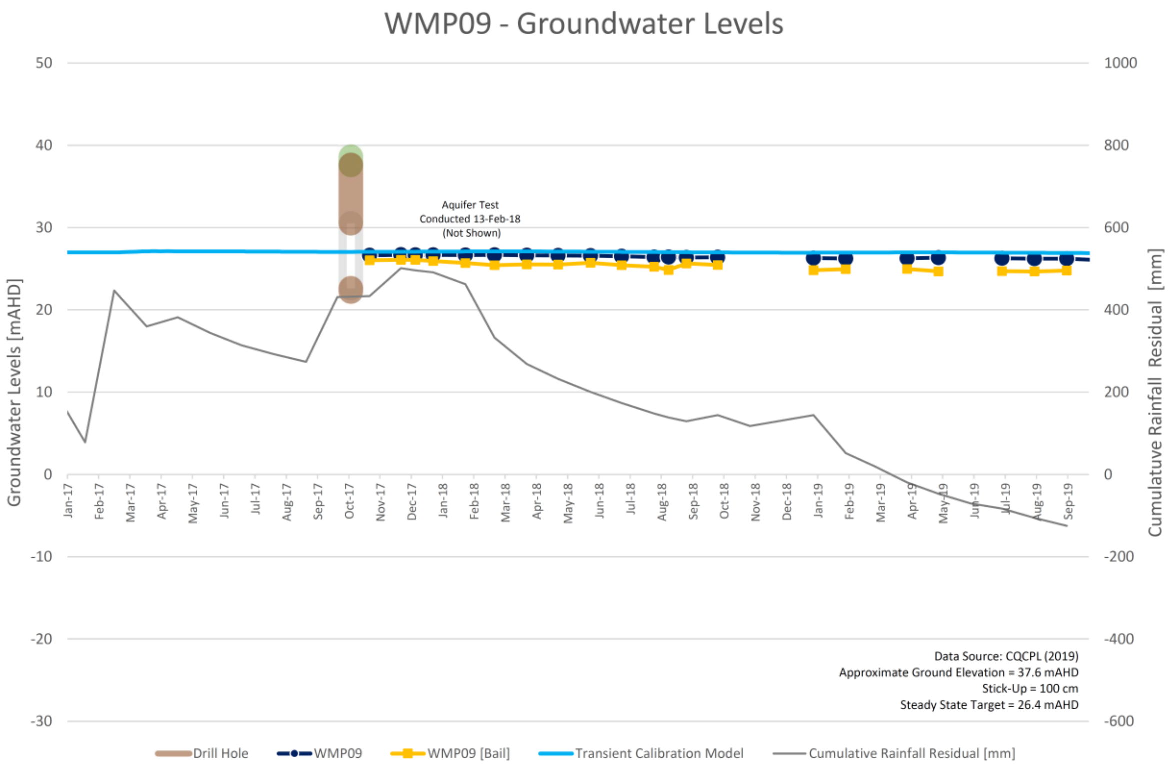
Graph A8-12: Cenozoic Deposits – Quaternary Pleistocene Alluvium / Regolith [WMP04]



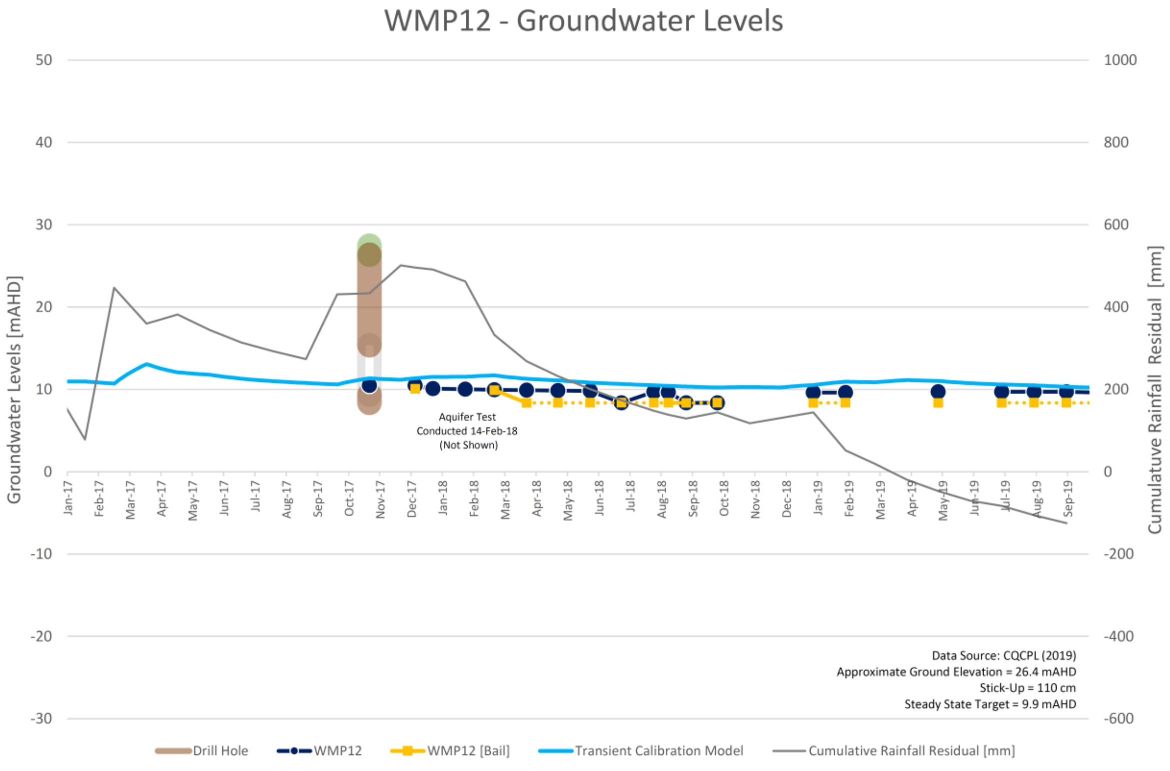
Aquifer Test
Conducted 13-Feb-18
(Not Shown)

Data Source: CQCPL (2019)
Approximate Ground Elevation = 43.5 mAHD
Stick-Up = 100 cm
Steady State Target = 33.4 mAHD

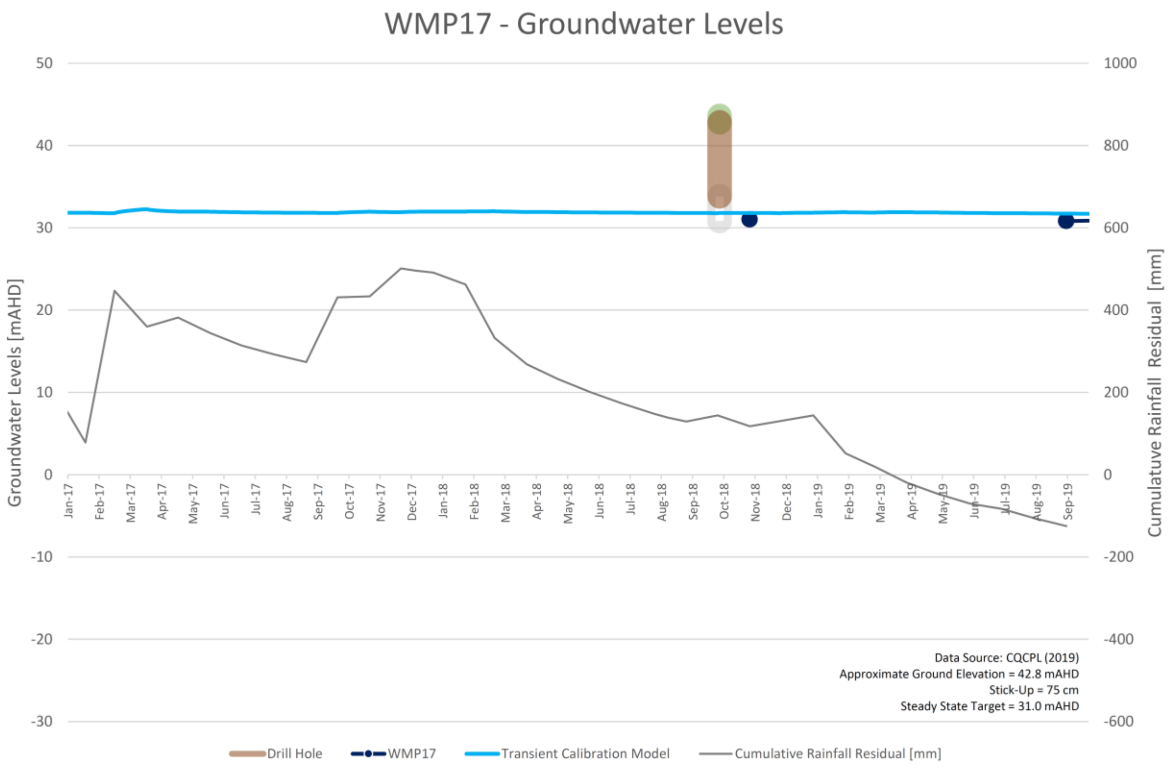
Graph A8-13: Cenozoic Deposits – Quaternary Pleistocene Alluvium / Regolith [WMP08]



Graph A8-14: Cenozoic Deposits – Quaternary Pleistocene Alluvium / Regolith [WMP09]

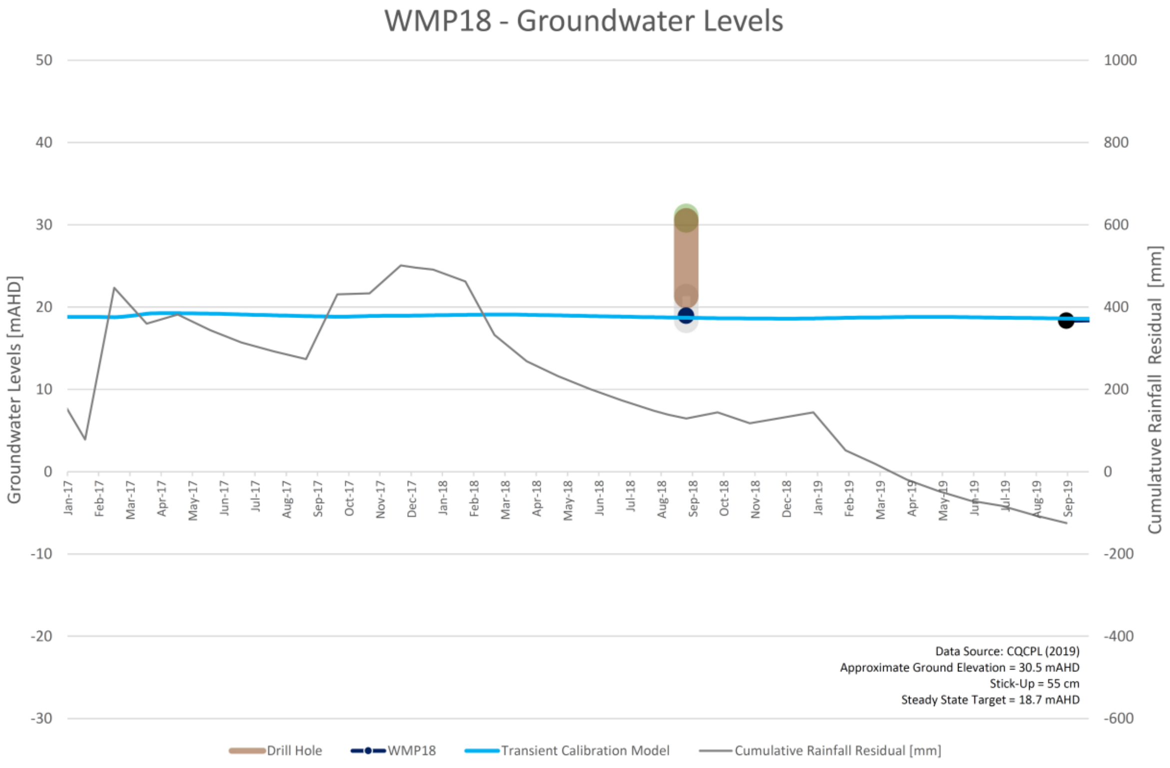


Graph A8-15: Cenozoic Deposits – Quaternary Pleistocene Alluvium / Regolith [WMP12]



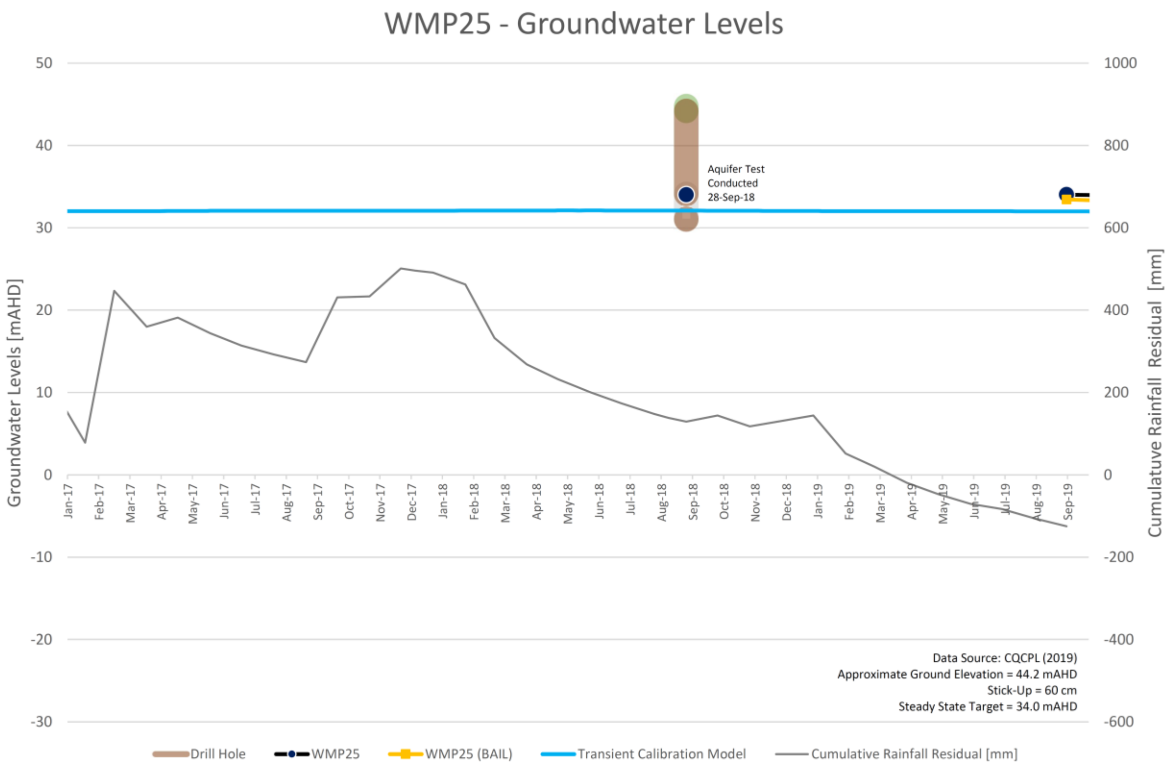
Data Source: CQCPL (2019)
Approximate Ground Elevation = 42.8 mAHD
Stick-Up = 75 cm
Steady State Target = 31.0 mAHD

*Graph A8-16: Cenozoic Deposits –
Quaternary Pleistocene Alluvium / Regolith
[WMP17]*

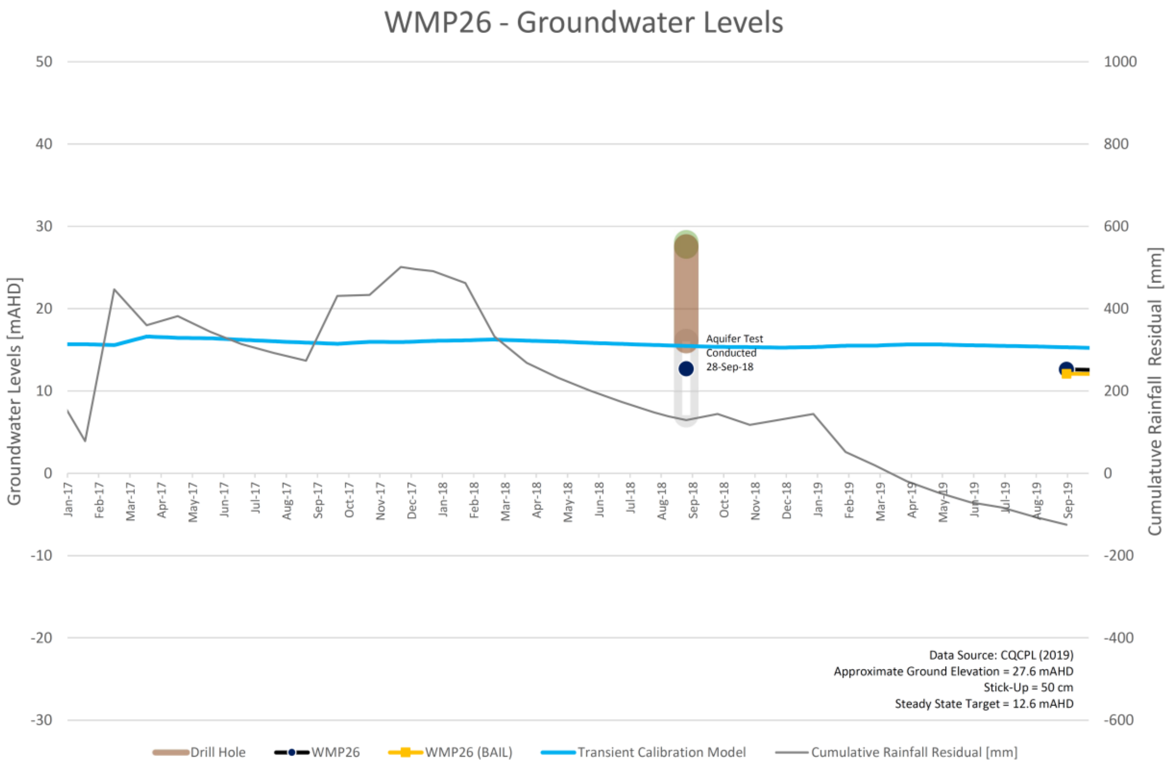


Data Source: CQCPL (2019)
Approximate Ground Elevation = 30.5 mAHD
Stick-Up = 55 cm
Steady State Target = 18.7 mAHD

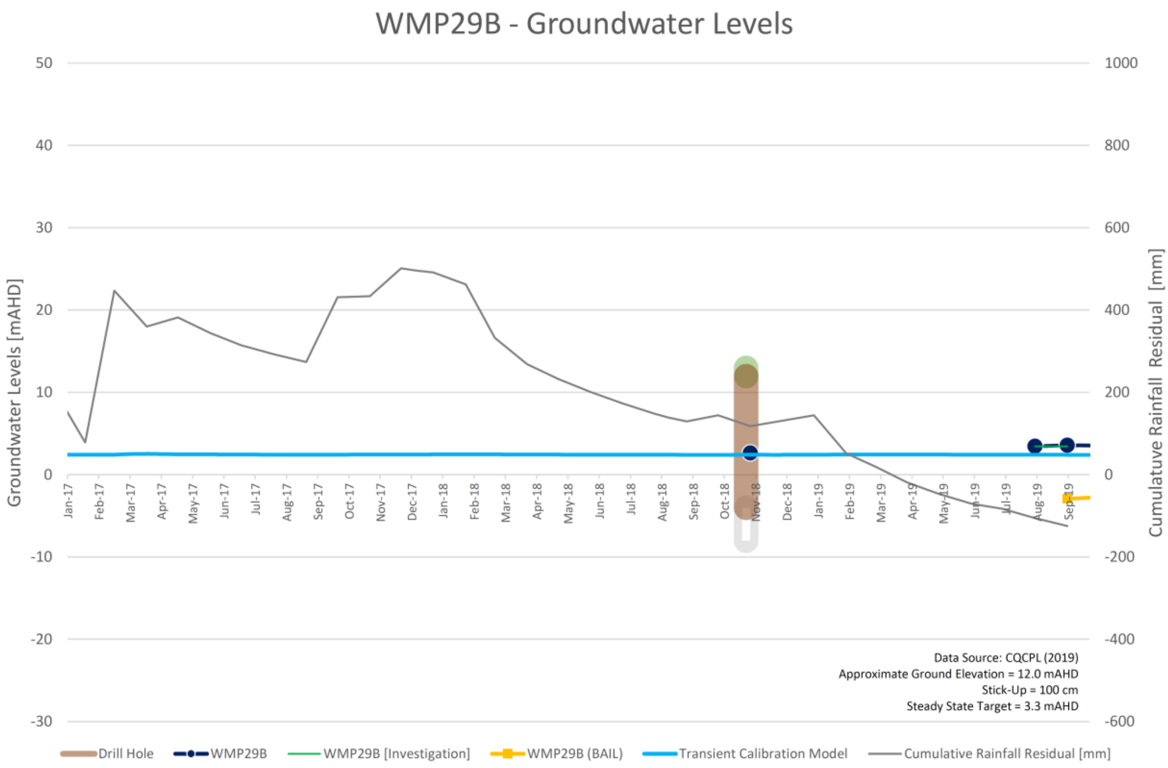
*Graph A8-17: Cenozoic Deposits –
Quaternary Pleistocene Alluvium / Regolith
[WMP18]*



Graph A8-18: Cenozoic Deposits – Quaternary Pleistocene Alluvium / Regolith [WMP25] [Wetland 1]

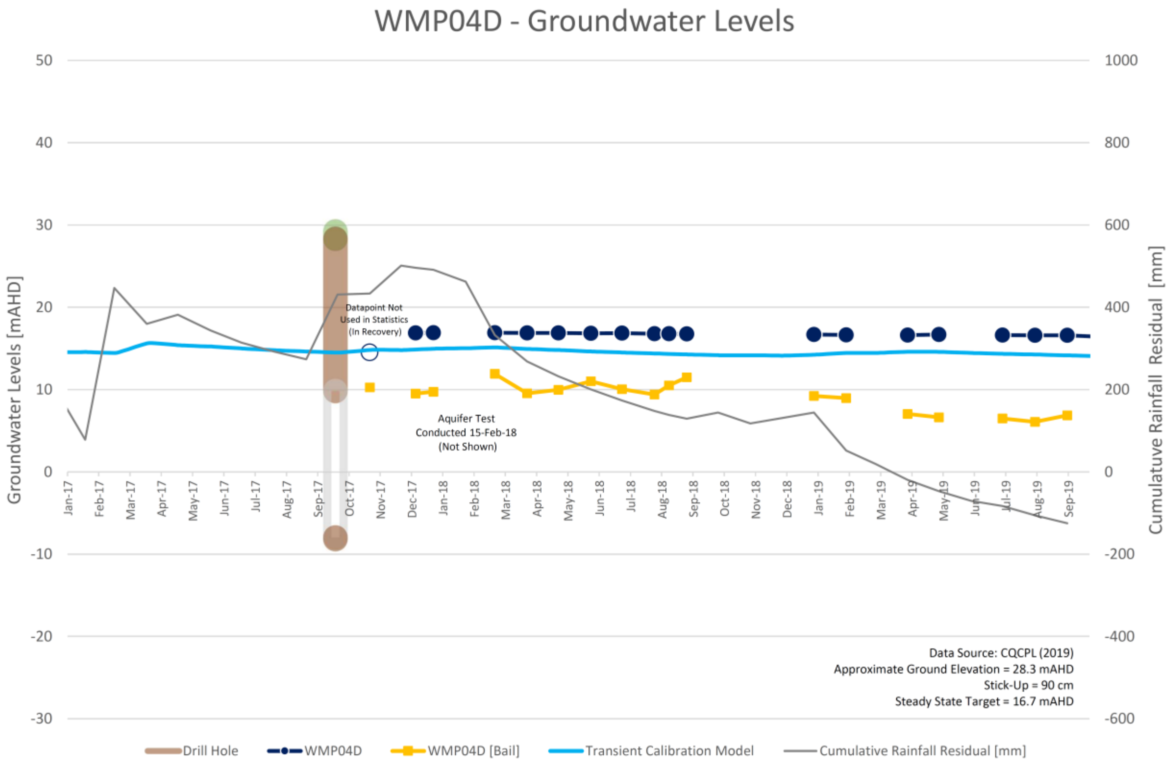


Graph A8-19: Cenozoic Deposits – Quaternary Pleistocene Alluvium / Regolith [WMP26]



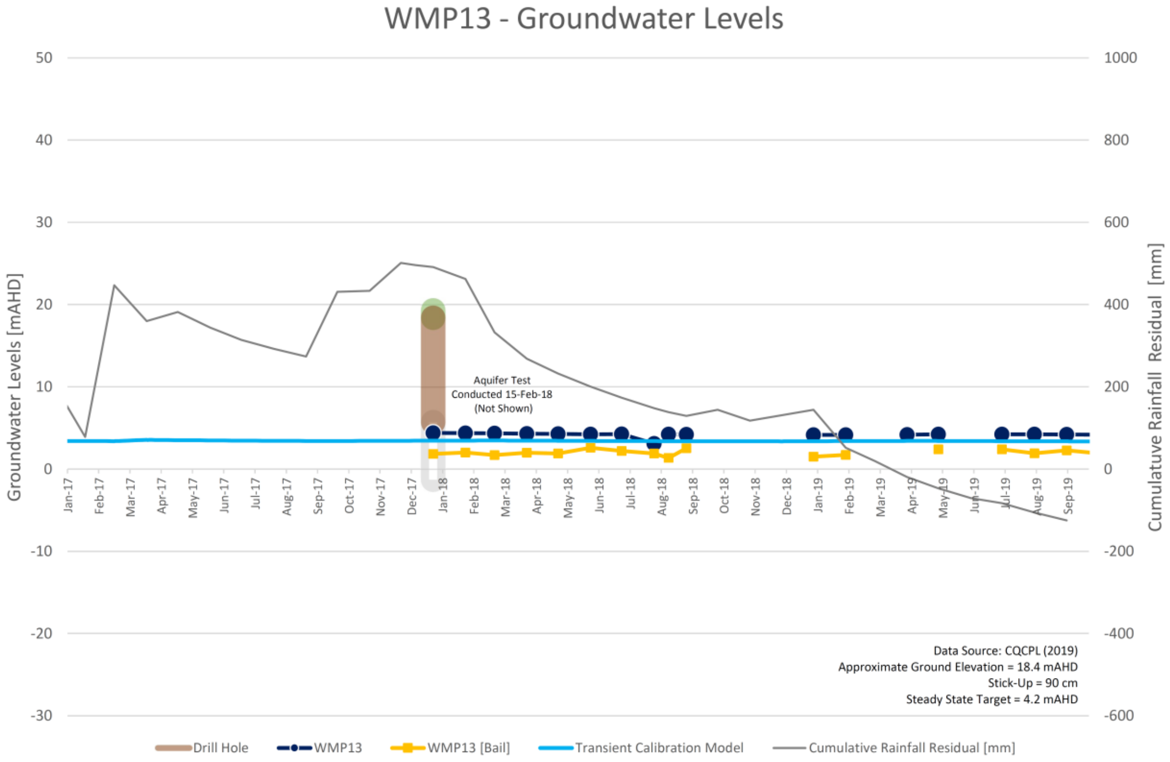
Data Source: CQCPL (2019)
Approximate Ground Elevation = 12.0 mAHD
Stick-Up = 100 cm
Steady State Target = 3.3 mAHD

Graph A8-20: Cenozoic Deposits –
Quaternary Pleistocene Alluvium / Regolith
[WMP29B]



Data Source: CQCPL (2019)
Approximate Ground Elevation = 28.3 mAHD
Stick-Up = 90 cm
Steady State Target = 16.7 mAHD

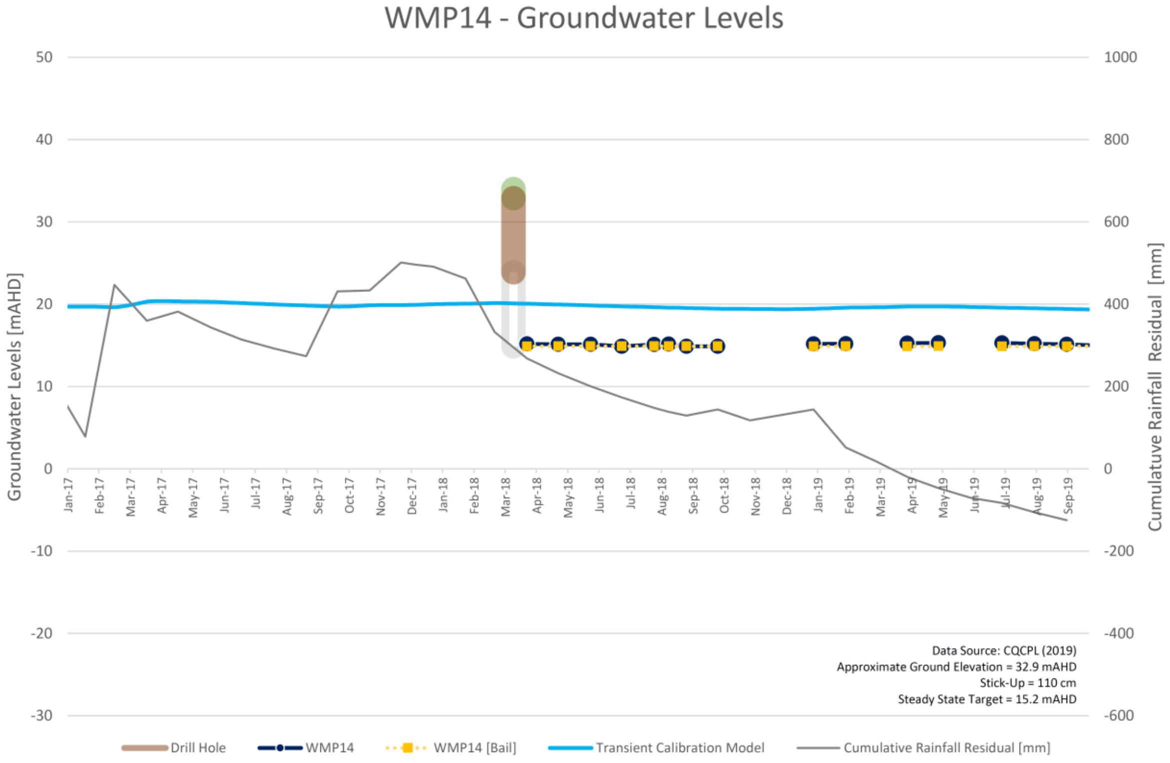
Graph A8-21: Styx Coal Measures –
Overburden (and Quaternary Alluvium [Lower] / Weathered Regolith
[WMP04D]



Aquifer Test Conducted 15-Feb-18 (Not Shown)

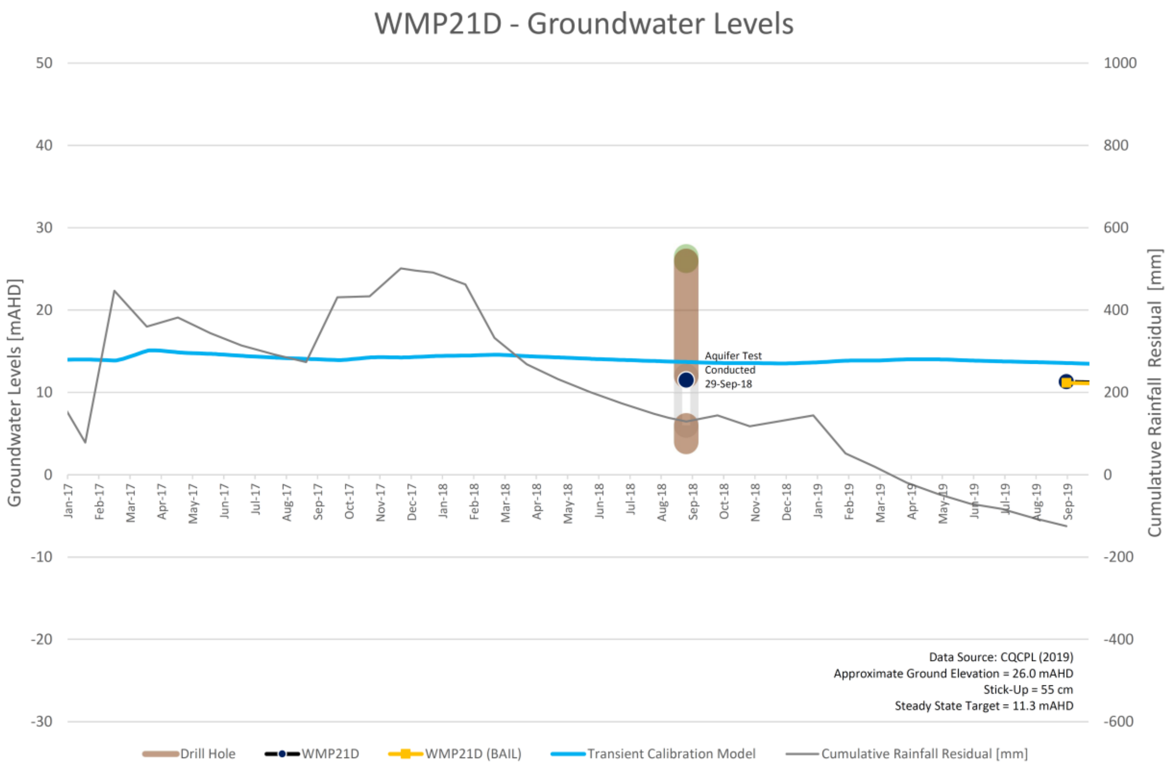
Data Source: CQCPL (2019)
Approximate Ground Elevation = 18.4 mAHD
Stick-Up = 90 cm
Steady State Target = 4.2 mAHD

Graph A8-22: Styx Coal Measures – Overburden (and Quaternary Alluvium [Lower] / Weathered Regolith [WMP13]

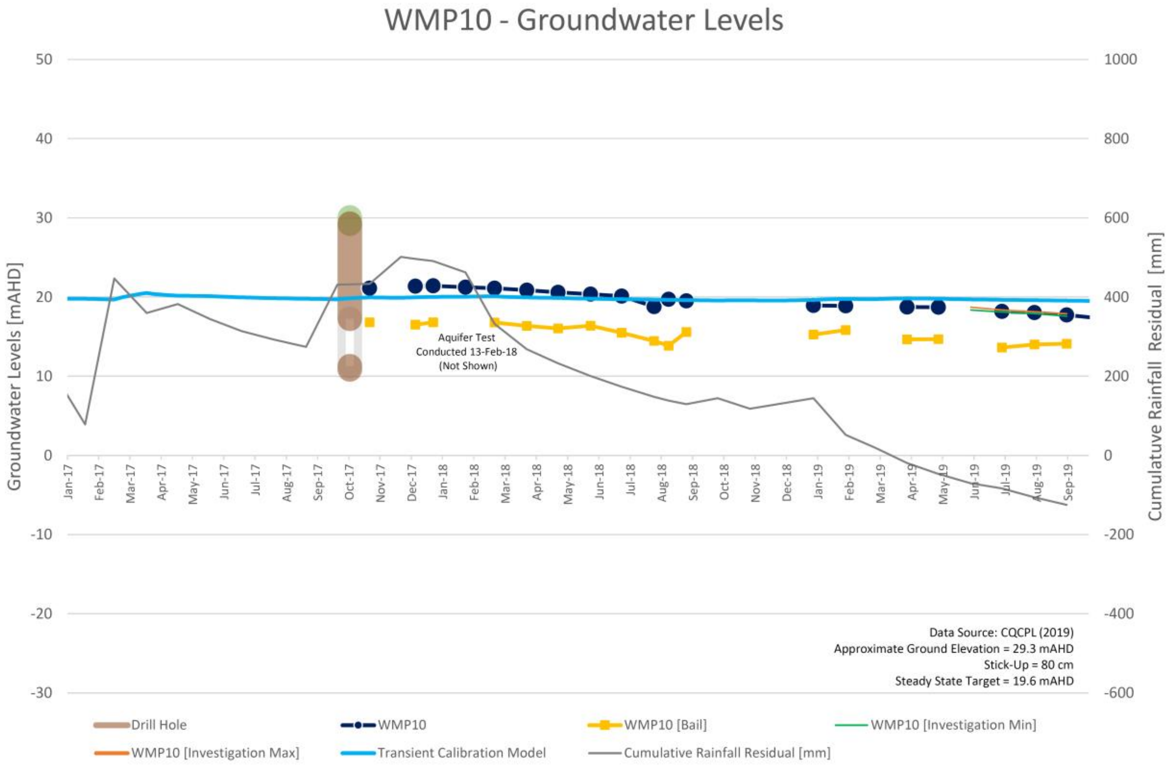


Data Source: CQCPL (2019)
Approximate Ground Elevation = 32.9 mAHD
Stick-Up = 110 cm
Steady State Target = 15.2 mAHD

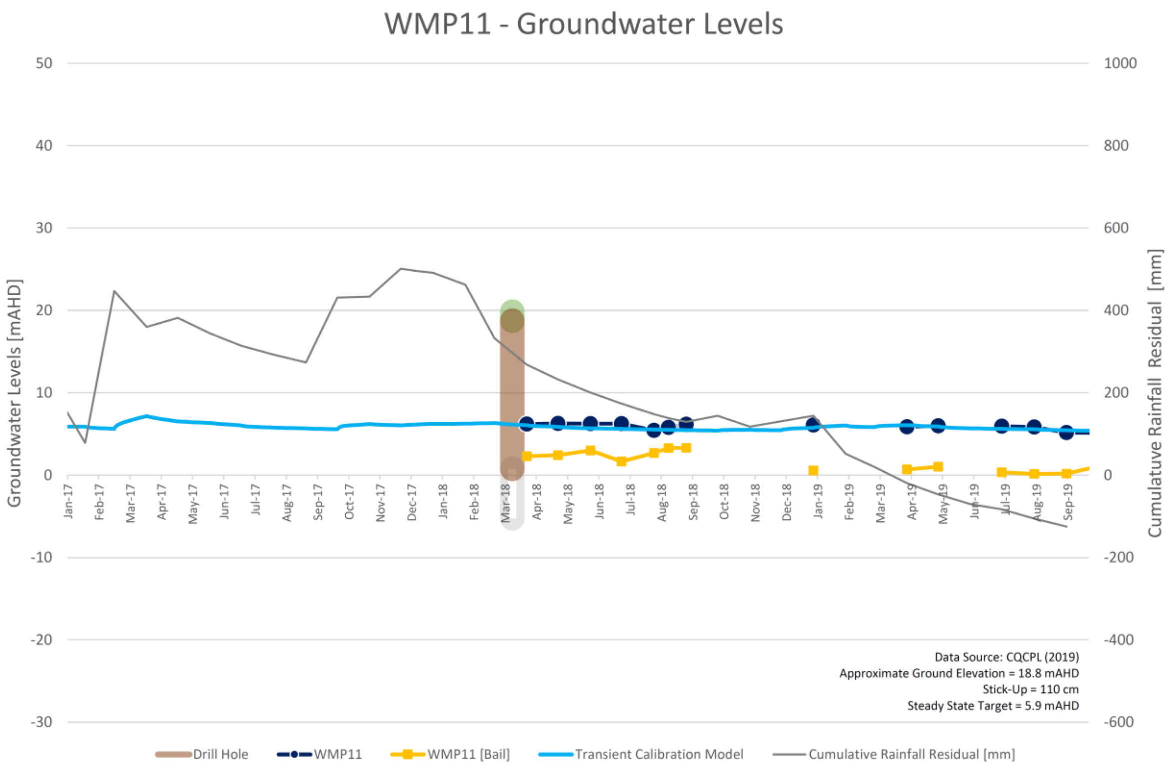
Graph A8-23: Styx Coal Measures – Overburden (and Quaternary Alluvium [Lower] / Weathered Regolith [WMP14]



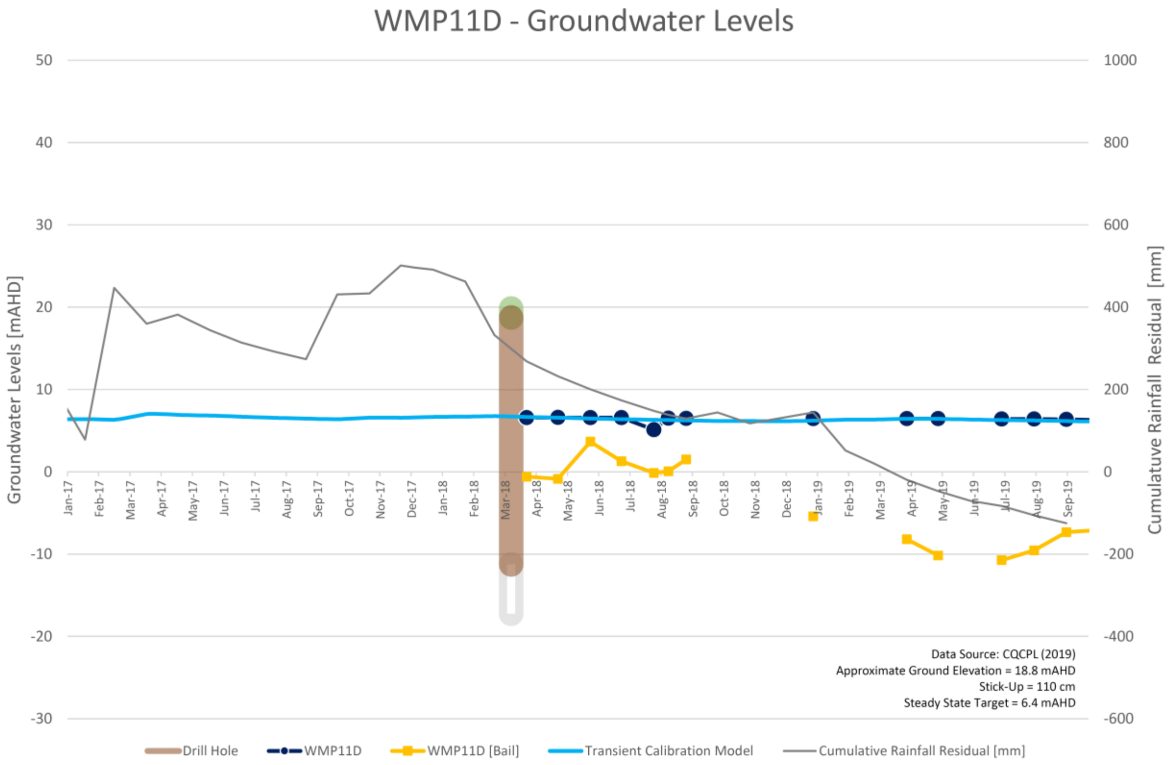
Graph A8-24: Styx Coal Measures – Overburden (and Quaternary Alluvium [Lower] / Weathered Regolith [WMP21D]



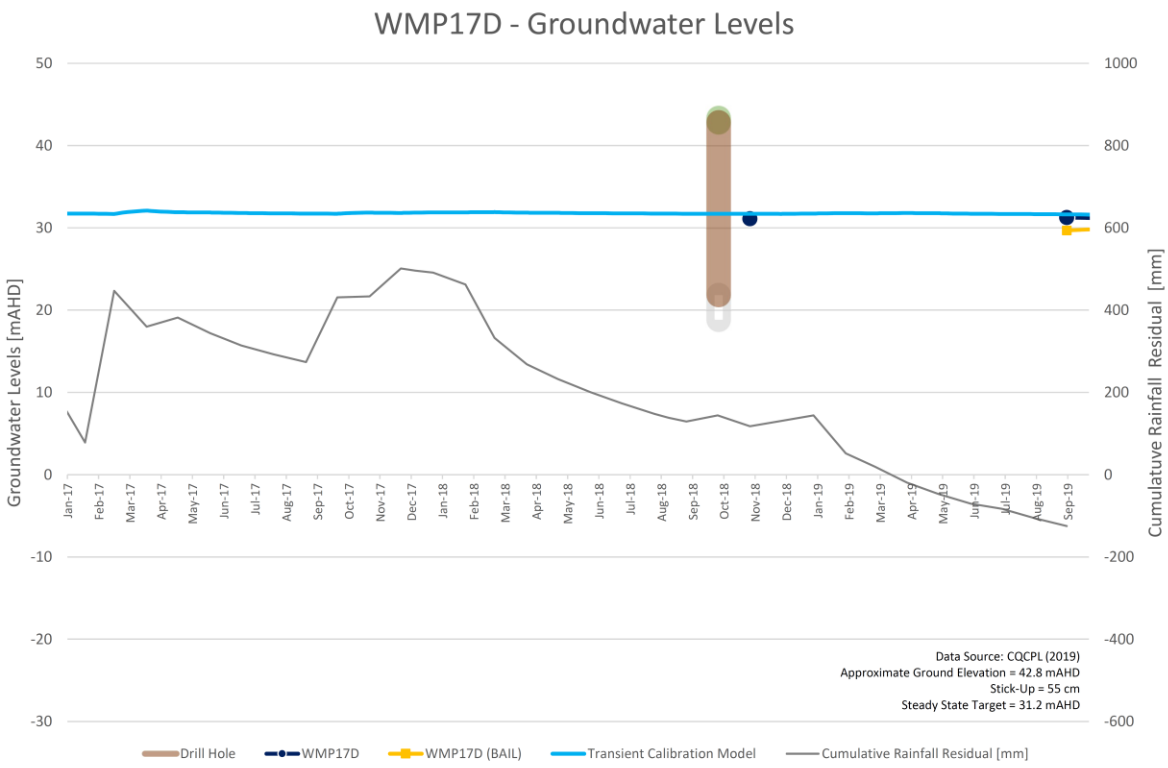
Graph A8-25: Styx Coal Measures – Overburden / Coal Seams and Interburden [WMP10]



Graph A8-26: Styx Coal Measures – Overburden / Coal Seams and Interburden [WMP11]

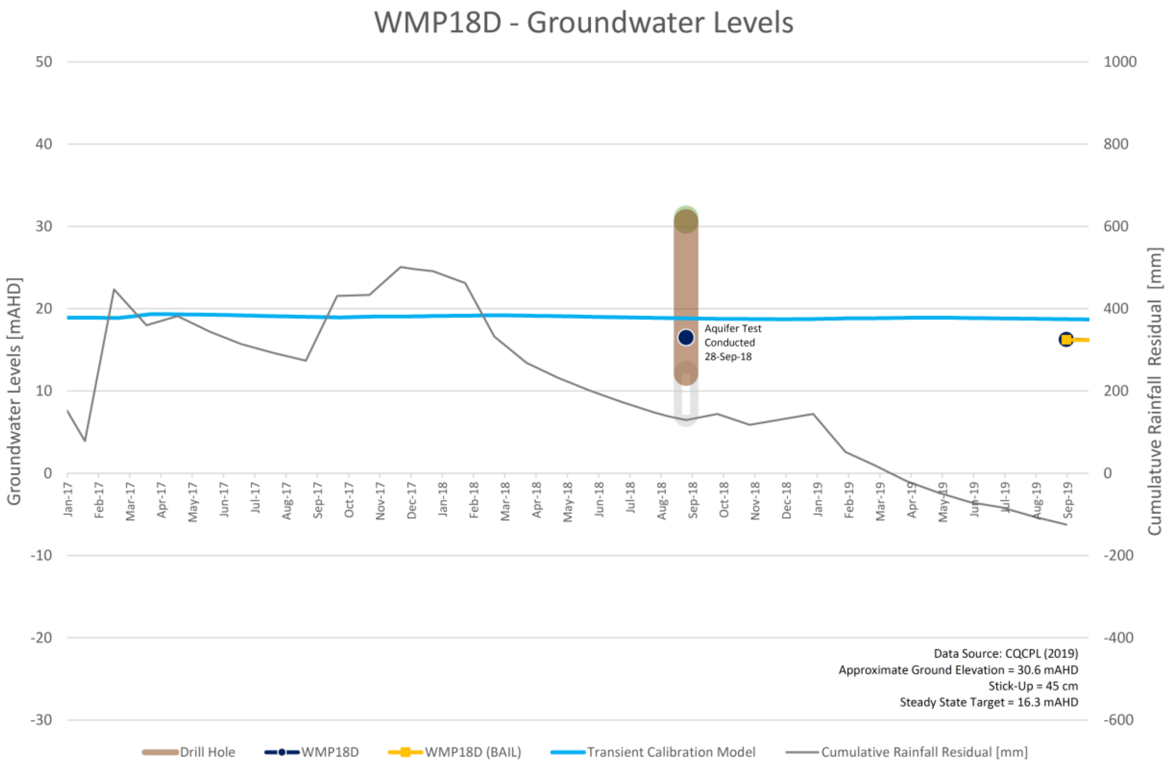


Graph A8-27: Styx Coal Measures – Overburden / Coal Seams and Interburden [WMP11D]



Data Source: CQCPL (2019)
Approximate Ground Elevation = 42.8 mAHD
Stick-Up = 55 cm
Steady State Target = 31.2 mAHD

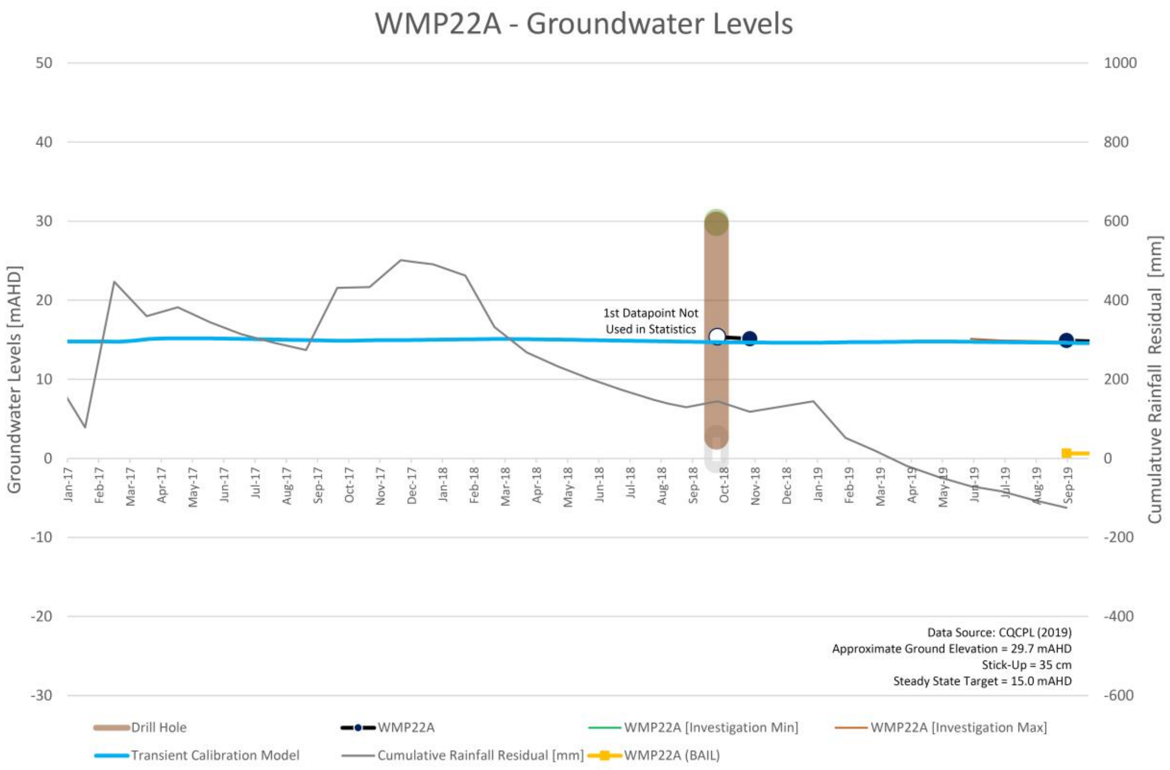
Graph A8-28: Styx Coal Measures – Overburden / Coal Seams and Interburden [WMP17D]



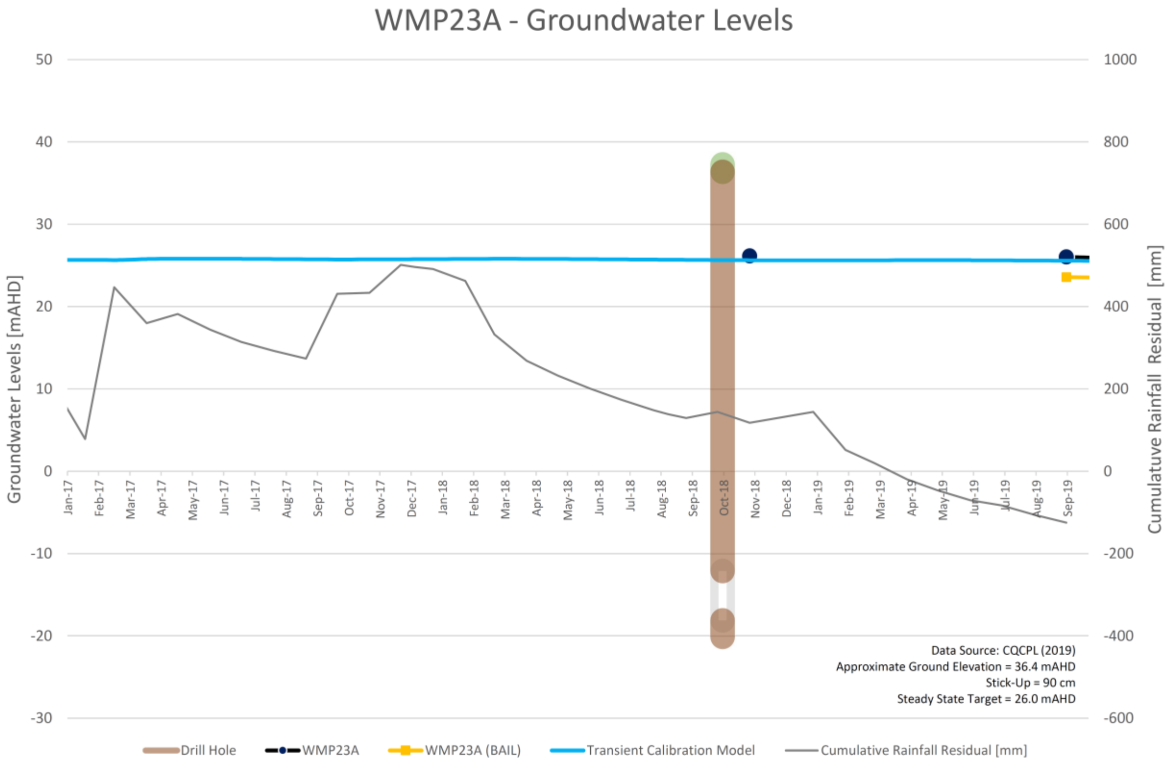
Aquifer Test
Conducted
28-Sep-18

Data Source: CQCPL (2019)
Approximate Ground Elevation = 30.6 mAHD
Stick-Up = 45 cm
Steady State Target = 16.3 mAHD

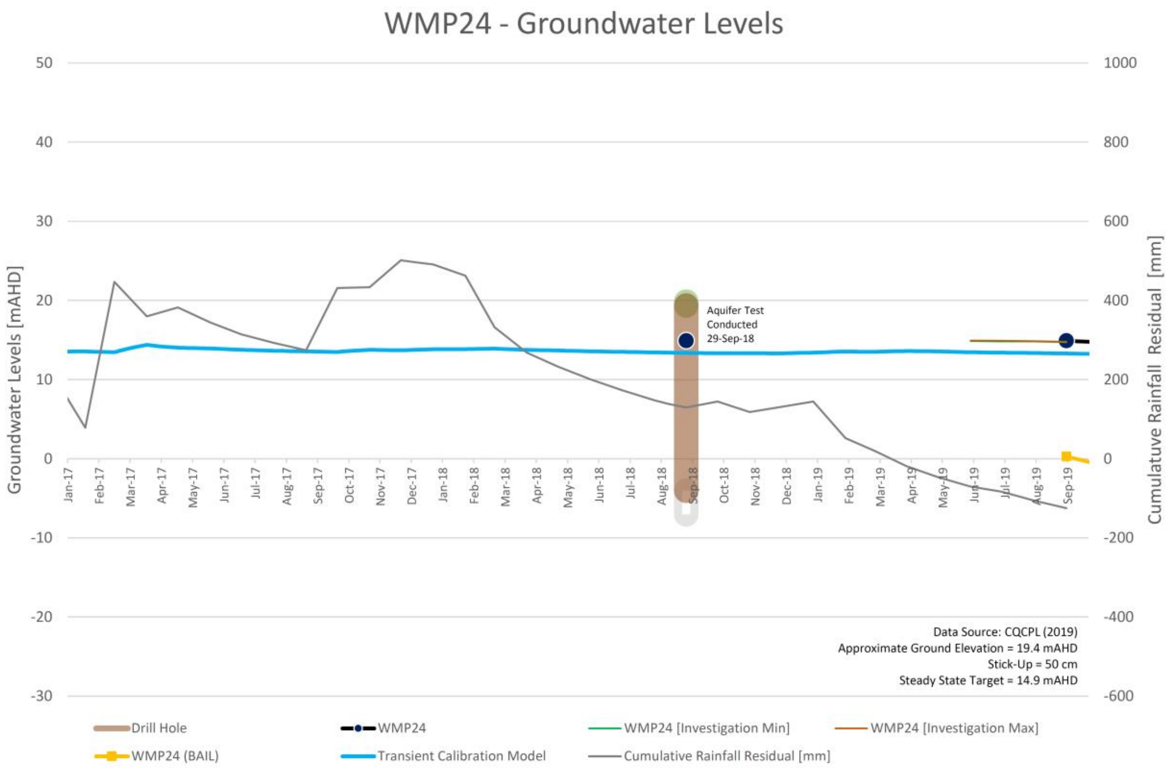
Graph A8-29: Styx Coal Measures – Overburden / Coal Seams and Interburden [WMP18D]



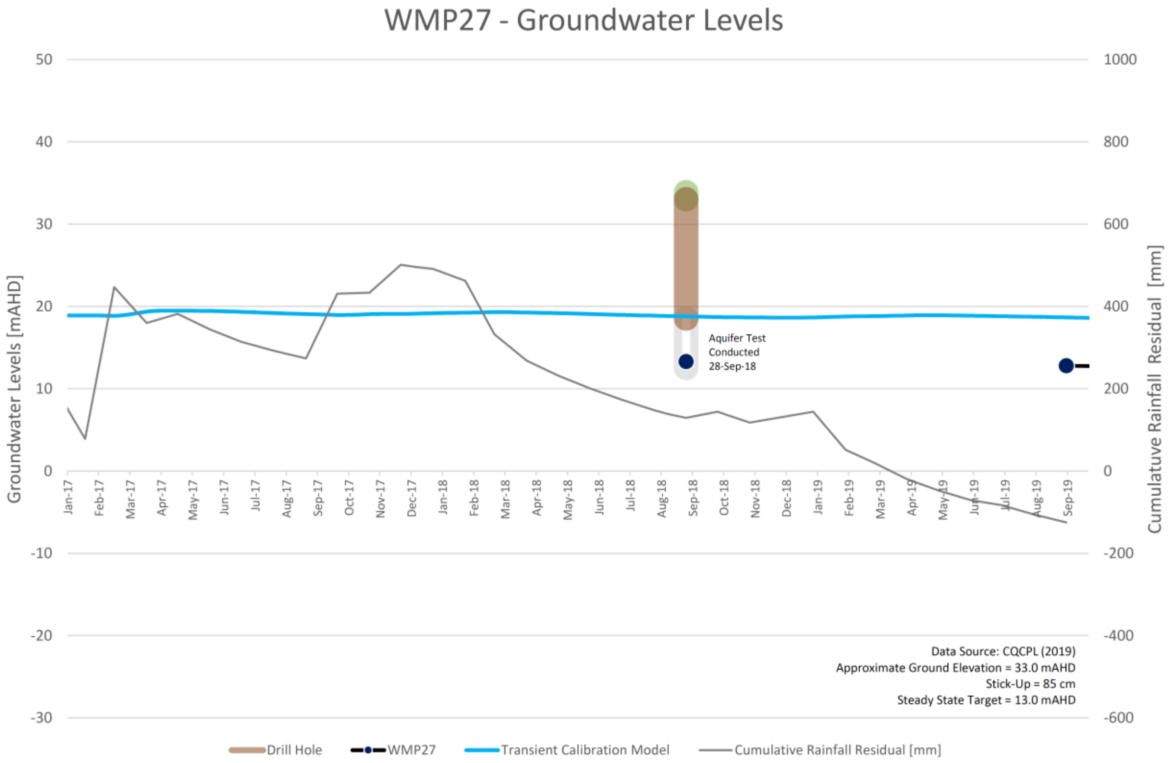
Graph A8-30: Styx Coal Measures – Overburden / Coal Seams and Interburden [WMP22A]



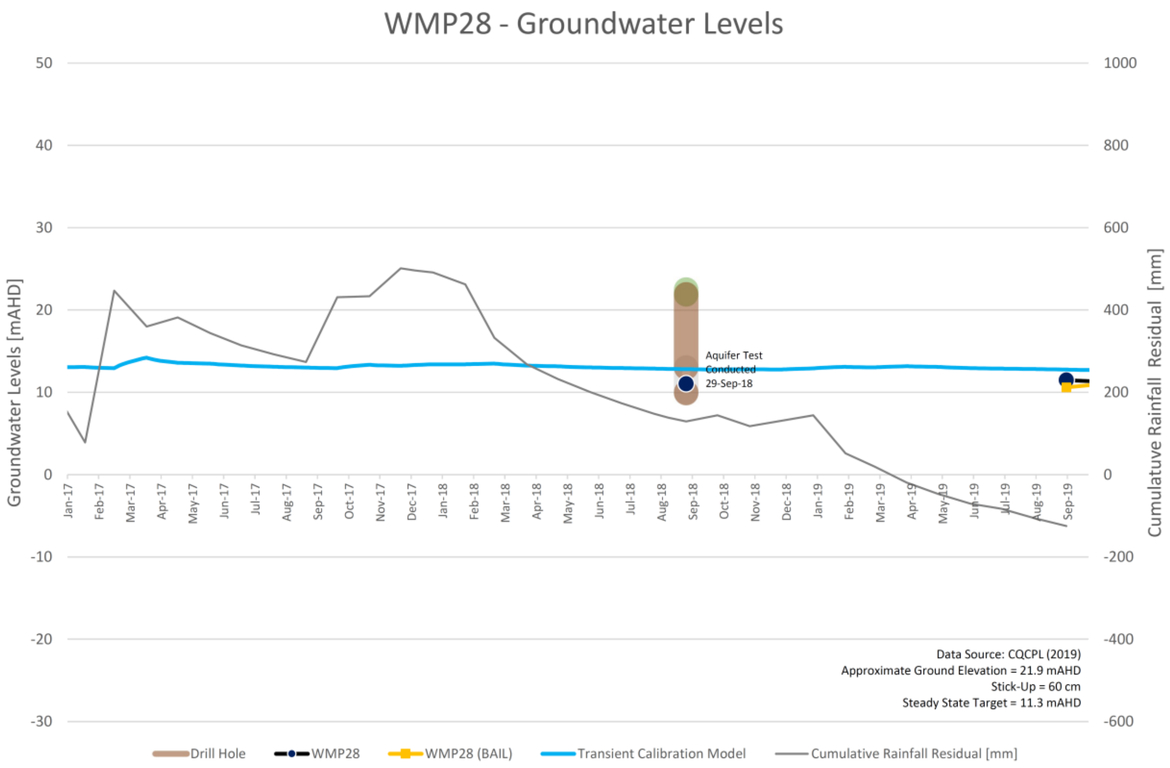
Graph A8-31: Styx Coal Measures – Overburden / Coal Seams and Interburden [WMP23A]



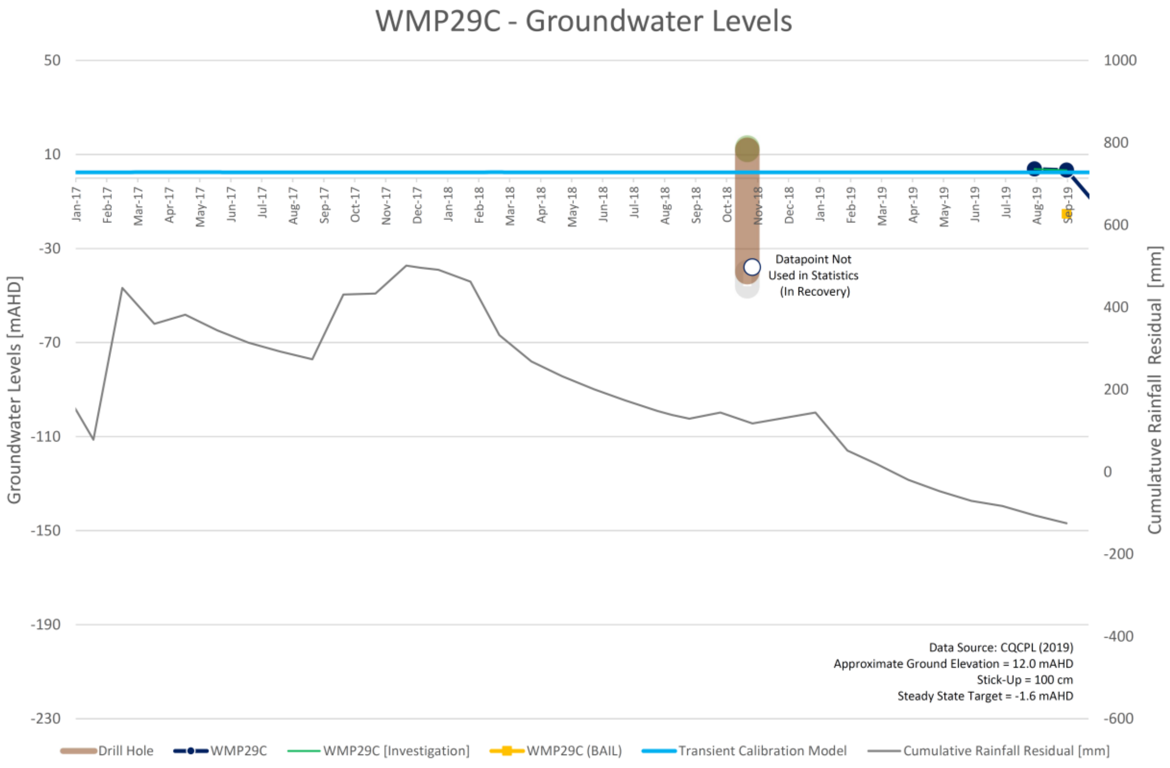
Graph A8-32: Styx Coal Measures – Overburden / Coal Seams and Interburden [WMP24]



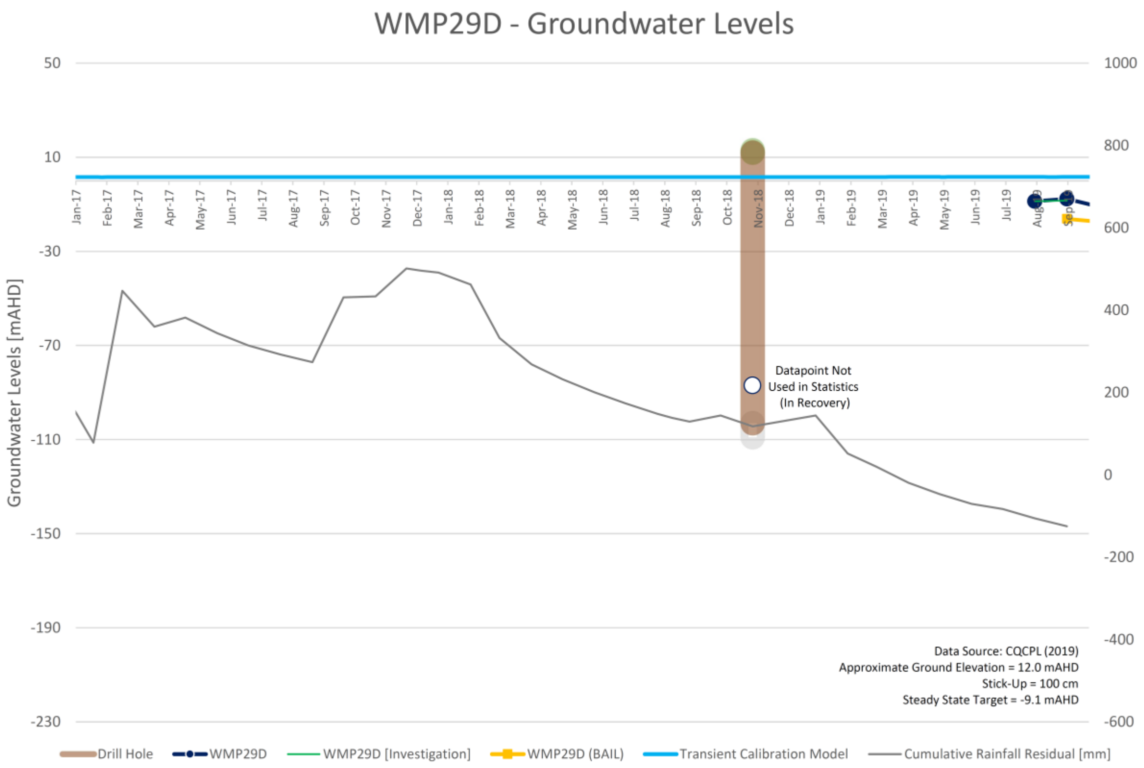
Graph A8-33: Styx Coal Measures – Overburden / Coal Seams and Interburden [WMP27]



Graph A8-34: Styx Coal Measures – Overburden / Coal Seams and Interburden [WMP28]



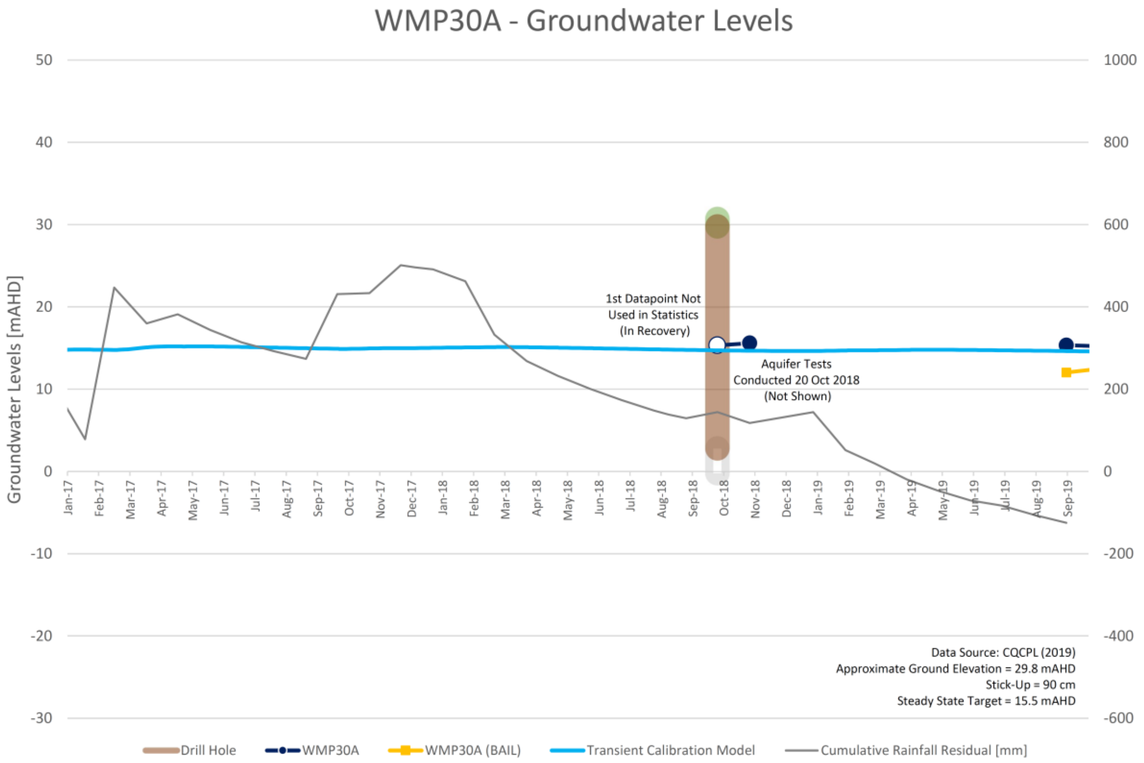
Graph A8-35: Styx Coal Measures – Overburden / Coal Seams and Interburden [WMP29C]



Datapoint Not
Used in Statistics
(In Recovery)

Data Source: CQCPL (2019)
Approximate Ground Elevation = 12.0 mAHD
Stick-Up = 100 cm
Steady State Target = -9.1 mAHD

Graph A8-36: Styx Coal Measures – Overburden / Coal Seams and Interburden [WMP29D]

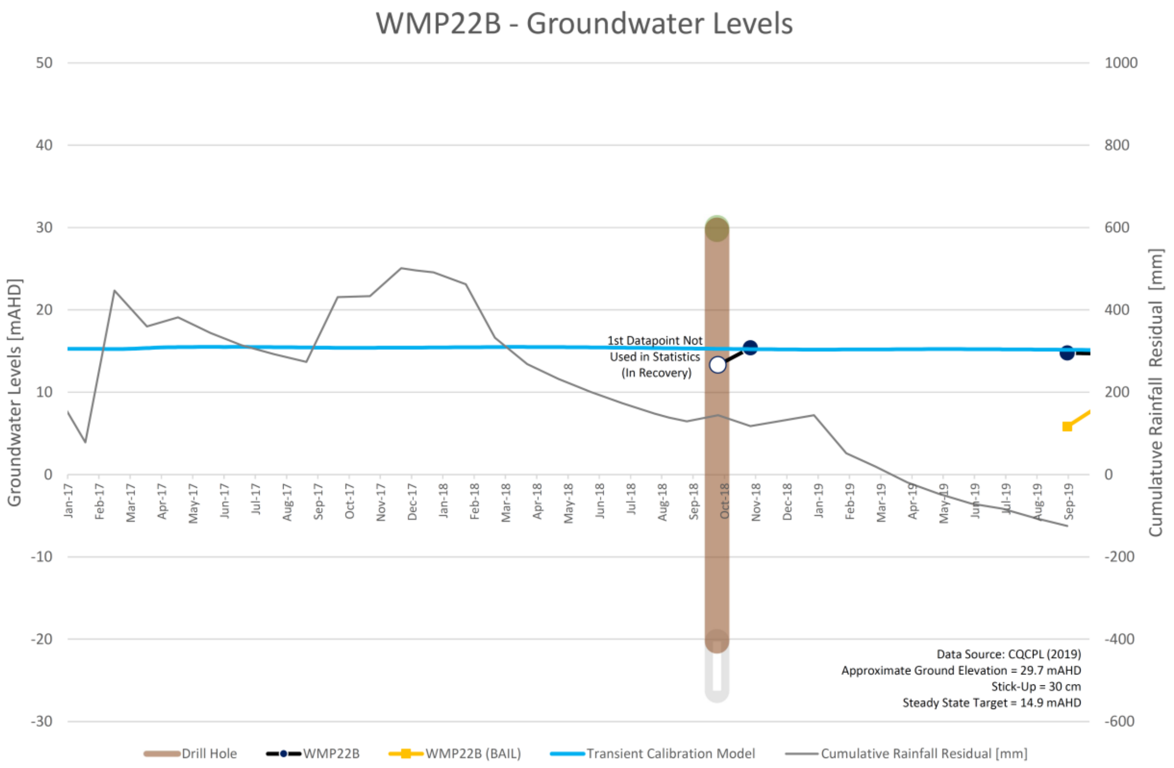


1st Datapoint Not
Used in Statistics
(In Recovery)

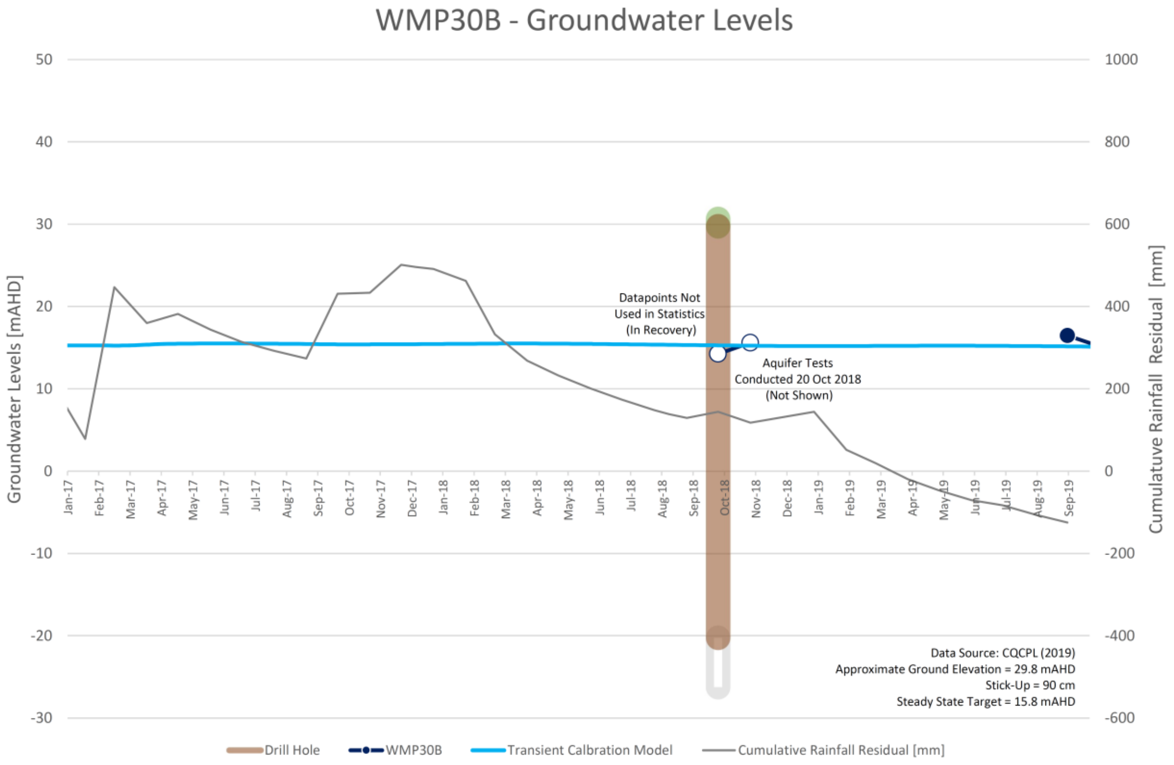
Aquifer Tests
Conducted 20 Oct 2018
(Not Shown)

Data Source: CQCPL (2019)
Approximate Ground Elevation = 29.8 mAHD
Stick-Up = 90 cm
Steady State Target = 15.5 mAHD

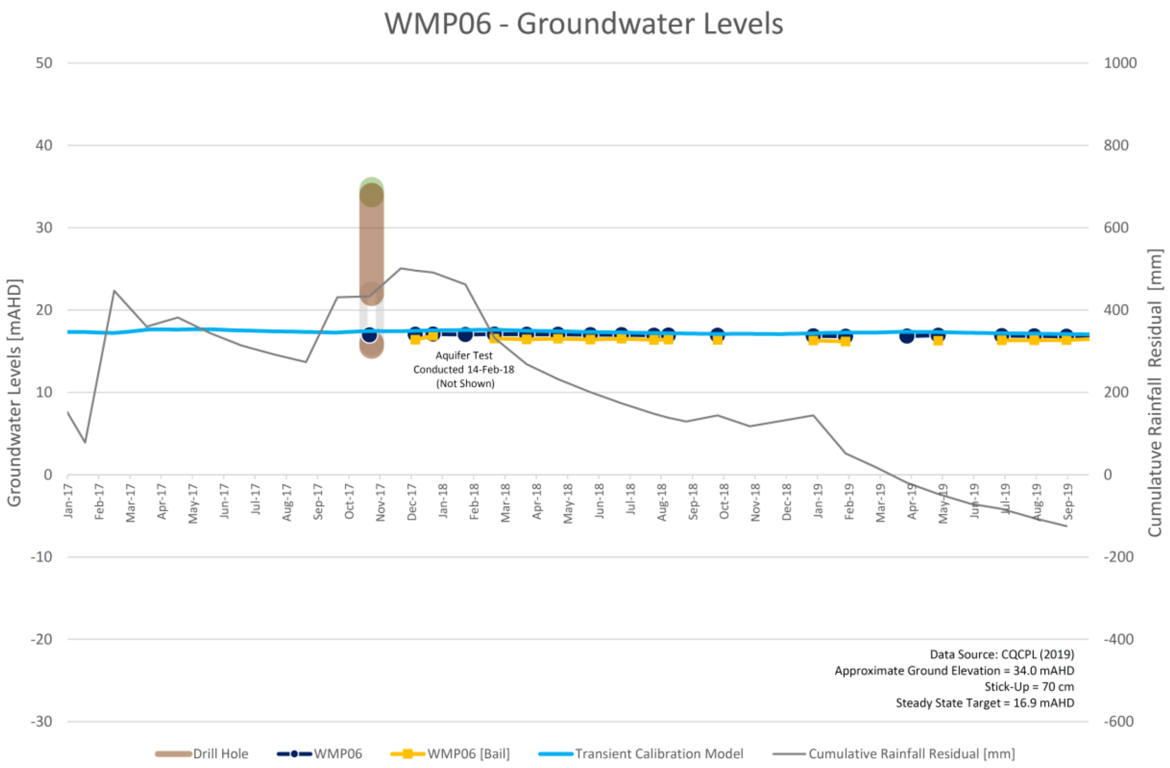
Graph A8-37: Styx Coal Measures – Overburden / Coal Seams and Interburden [WMP30A]



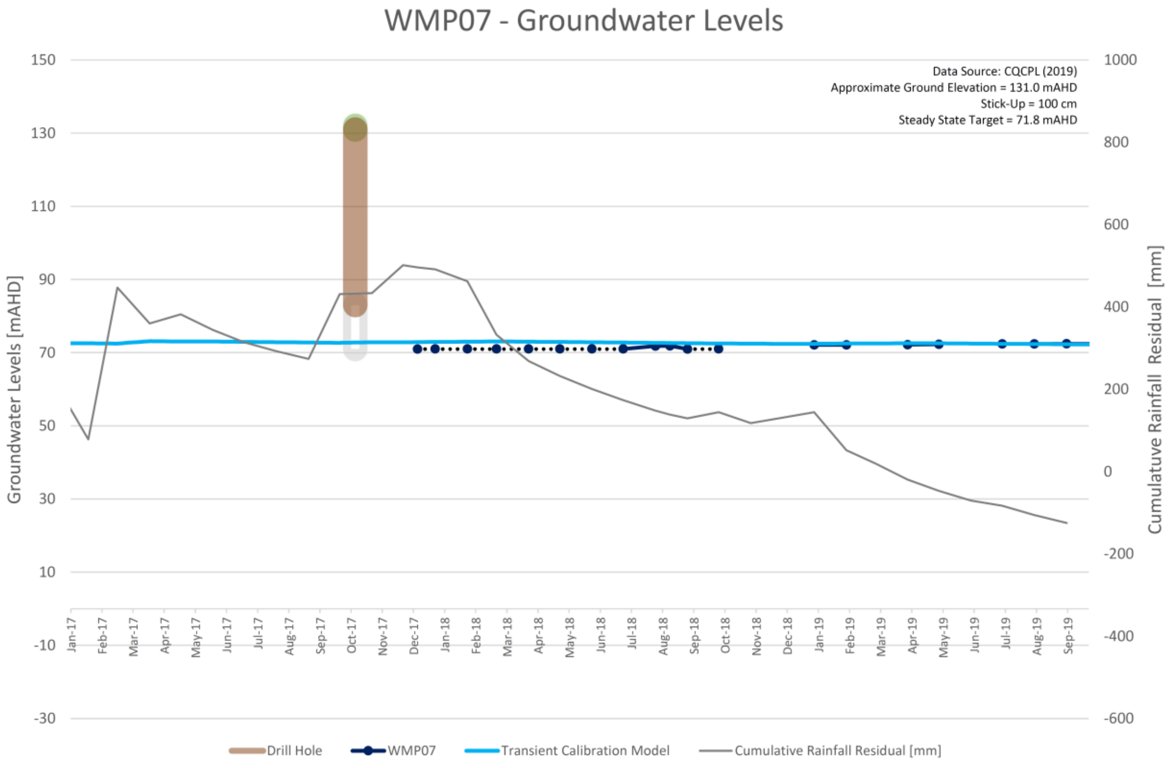
Graph A8-38: Styx Coal Measures – Coal Seams [WMP22B]



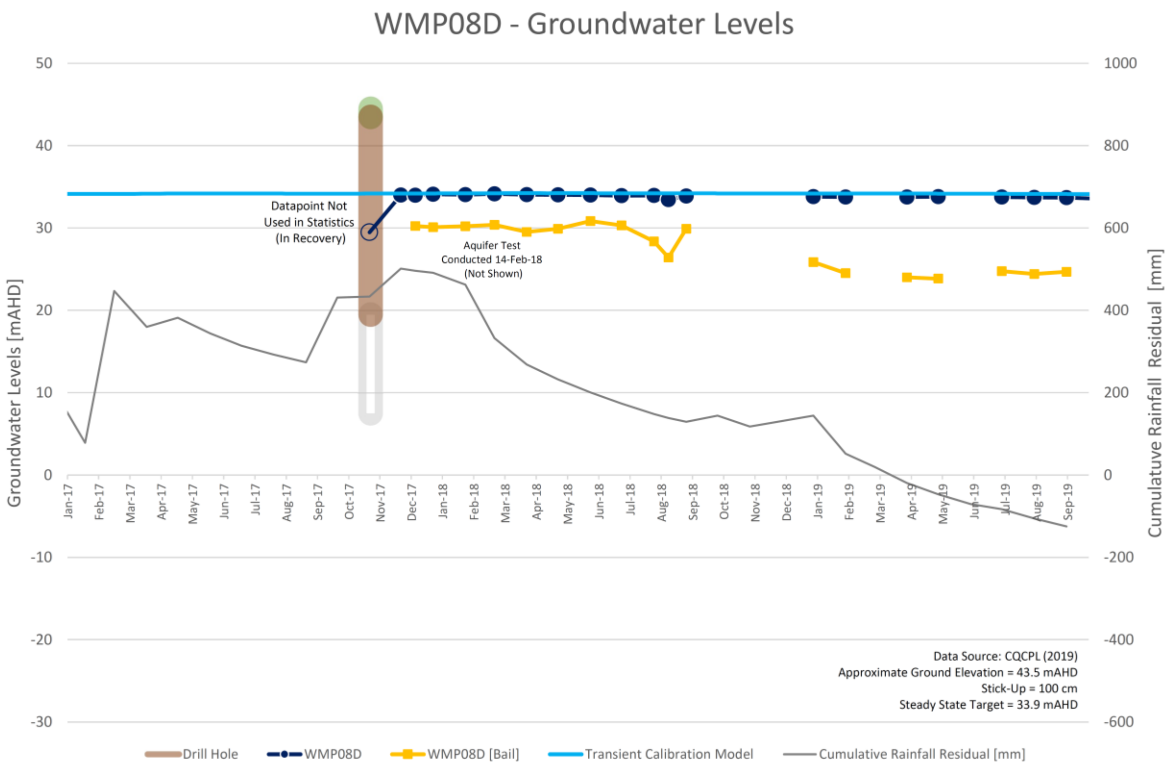
Graph A8-39: Styx Coal Measures – Coal Seams [WMP30B]



Graph A8-40: Styx Coal Measures –
Underburden (and Quaternary Alluvium [Lower]) / Weathered Regolith
[WMP06]

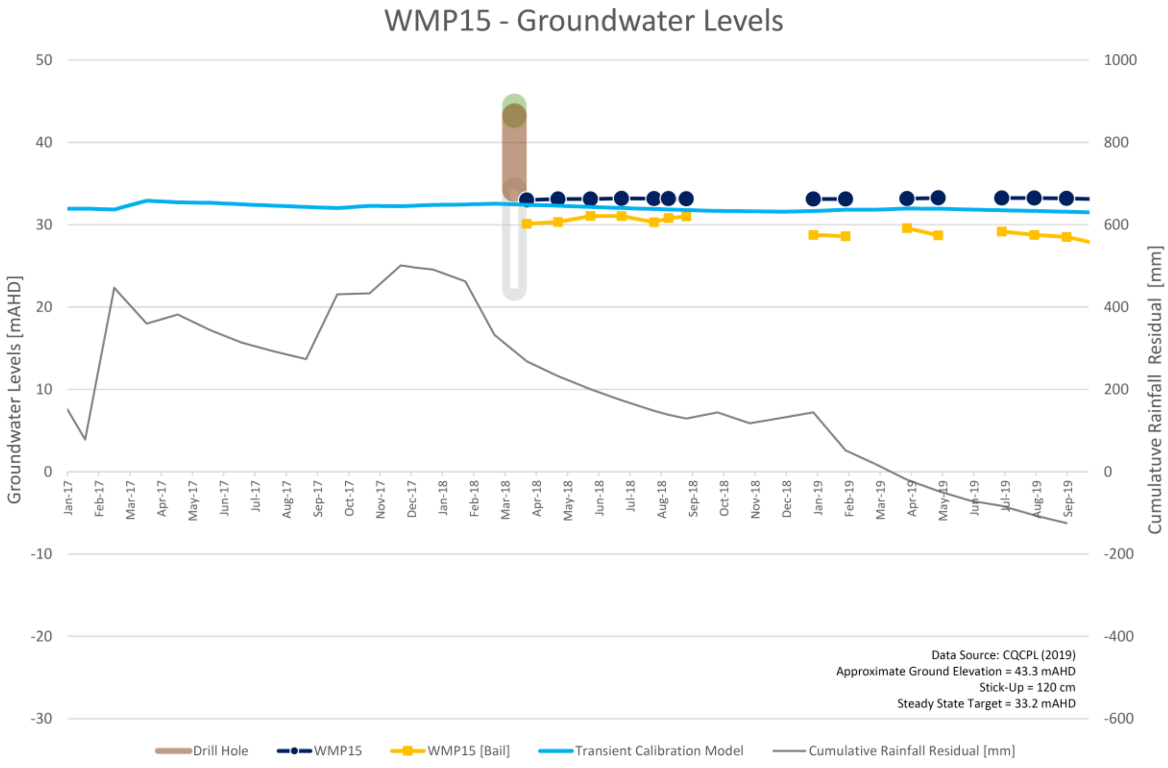


Graph A8-41: Styx Coal Measures –
Underburden
[WMP07]



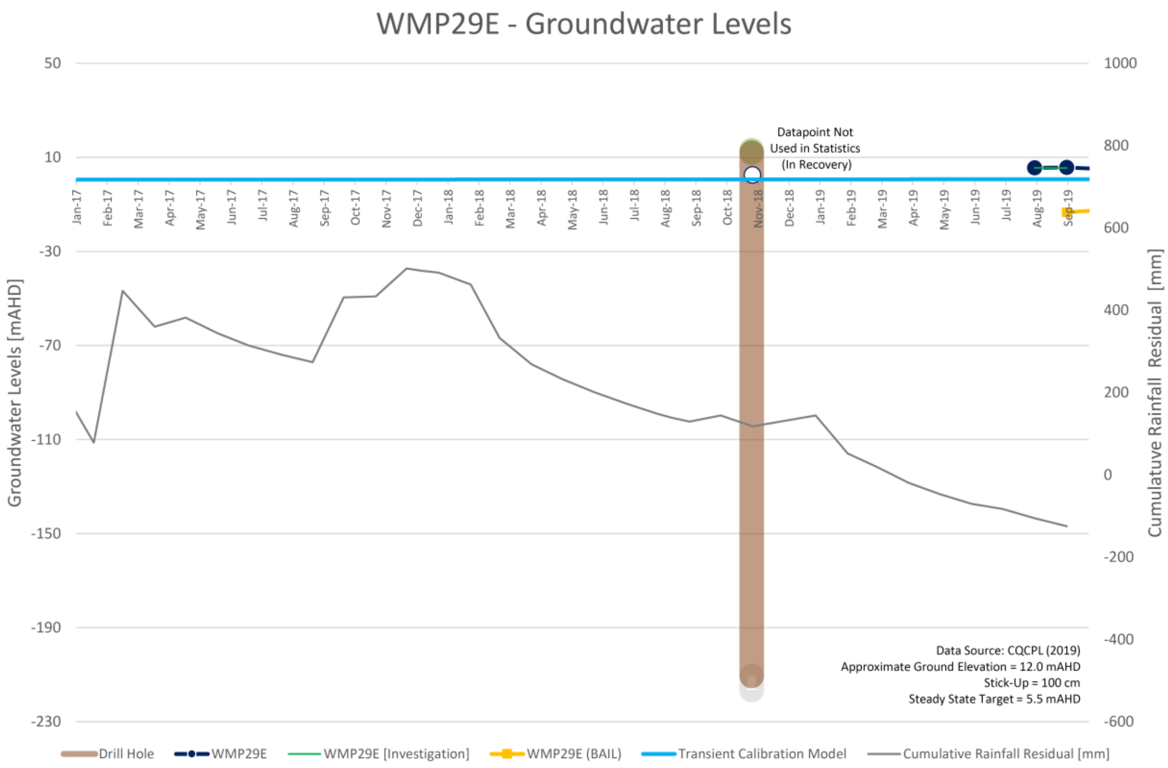
Data Source: CQCPL (2019)
Approximate Ground Elevation = 43.5 mAHD
Stick-Up = 100 cm
Steady State Target = 33.9 mAHD

Graph A8-42: Styx Coal Measures – Underburden [WMP08D]

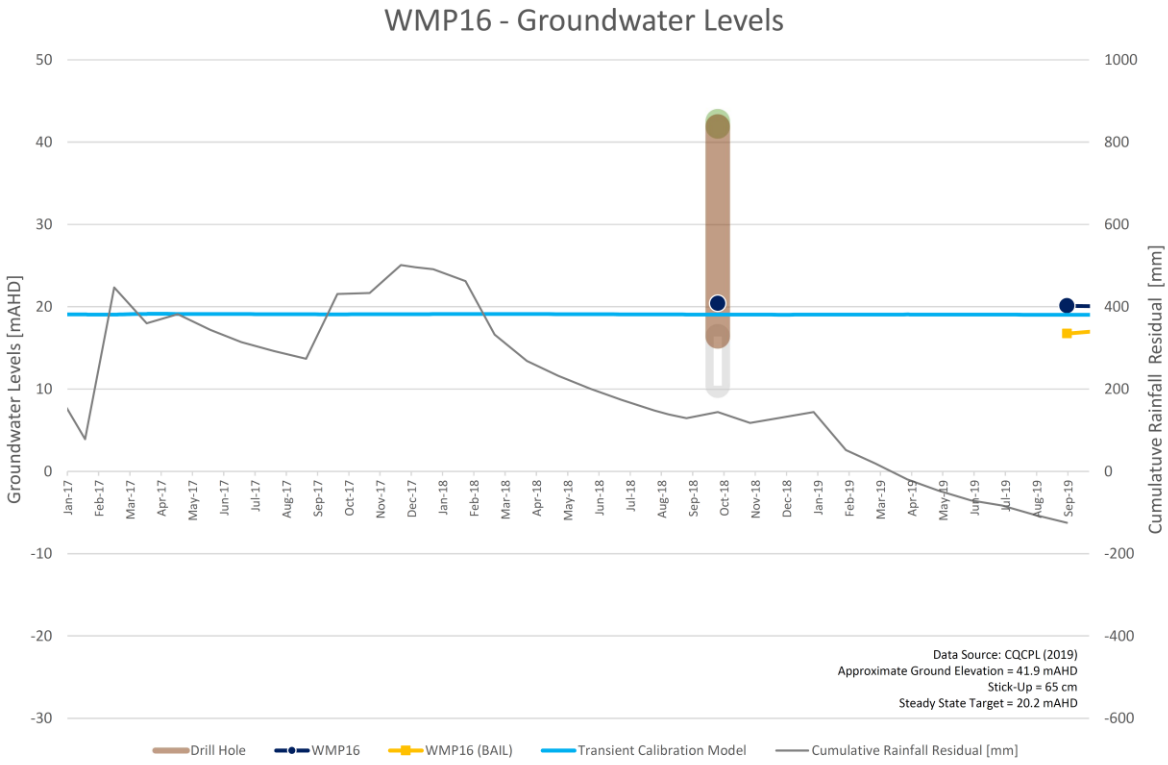


Data Source: CQCPL (2019)
Approximate Ground Elevation = 43.3 mAHD
Stick-Up = 120 cm
Steady State Target = 33.2 mAHD

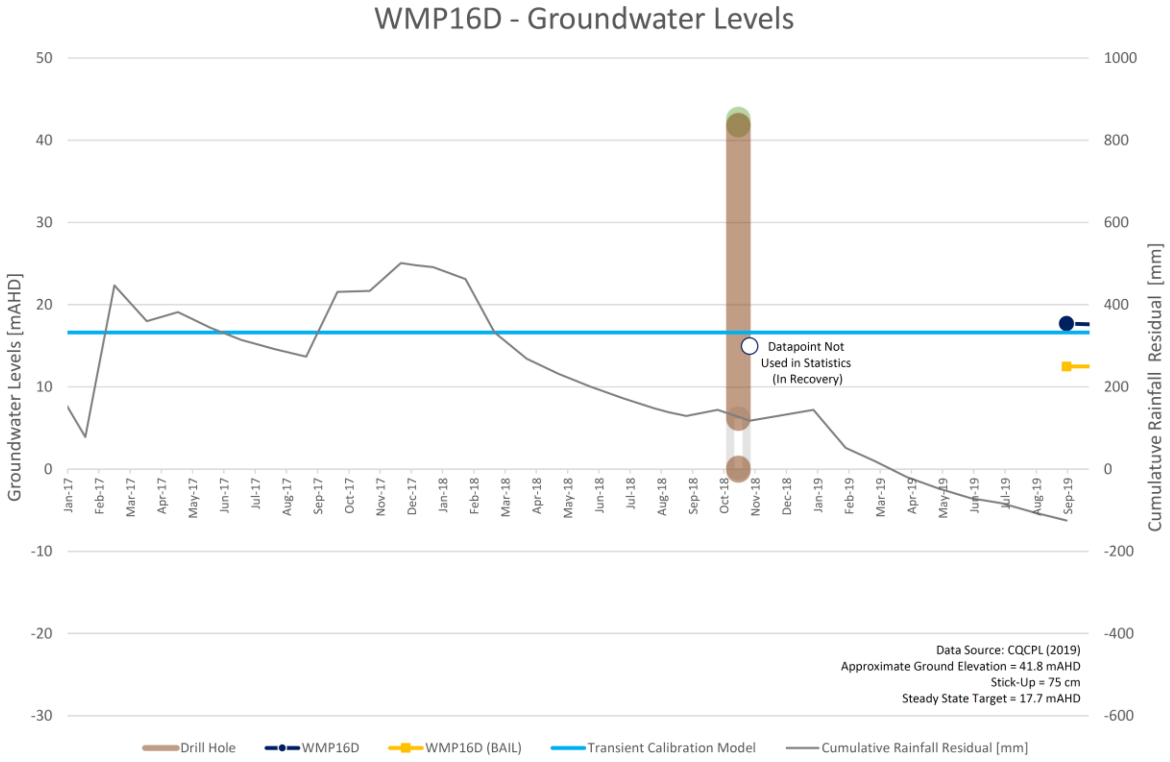
Graph A8-43: Permian Measures – Back Creek Group (and Styx Coal Measures – Underburden) [WMP15]



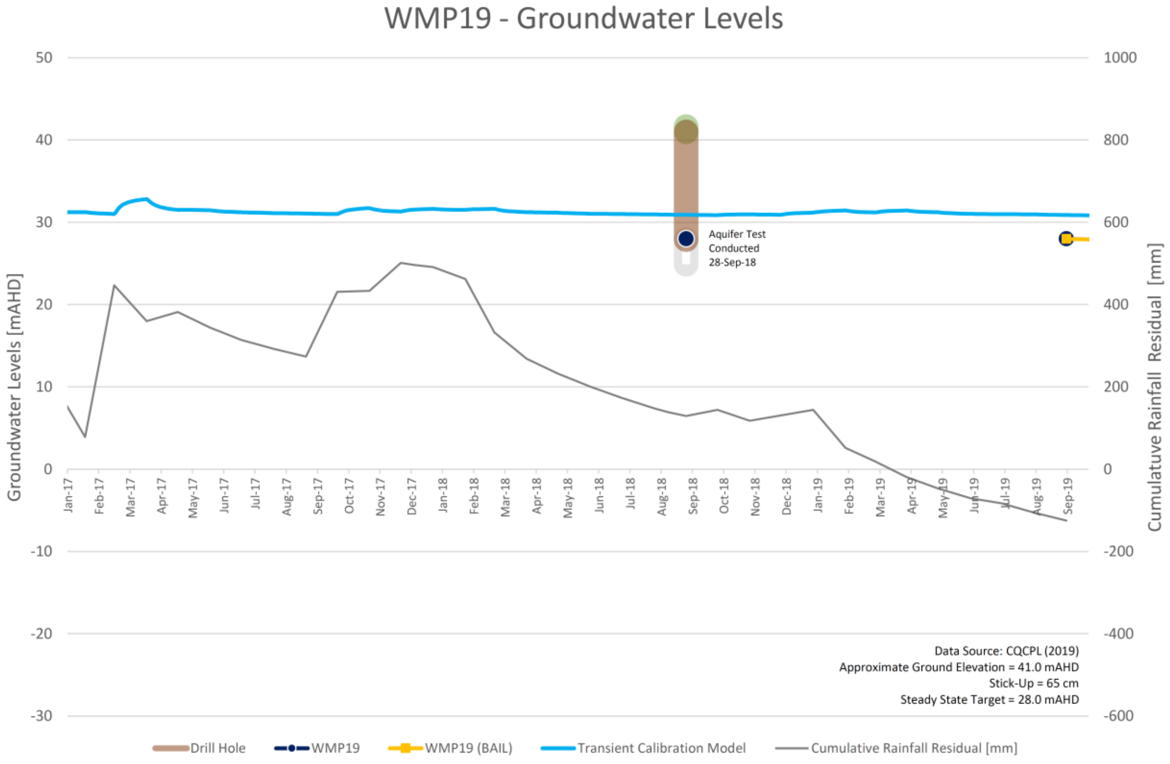
Graph A8-44: Permian Measures –
Back Creek Group (and Styx Coal Measures – Underburden)
[WMP29E]



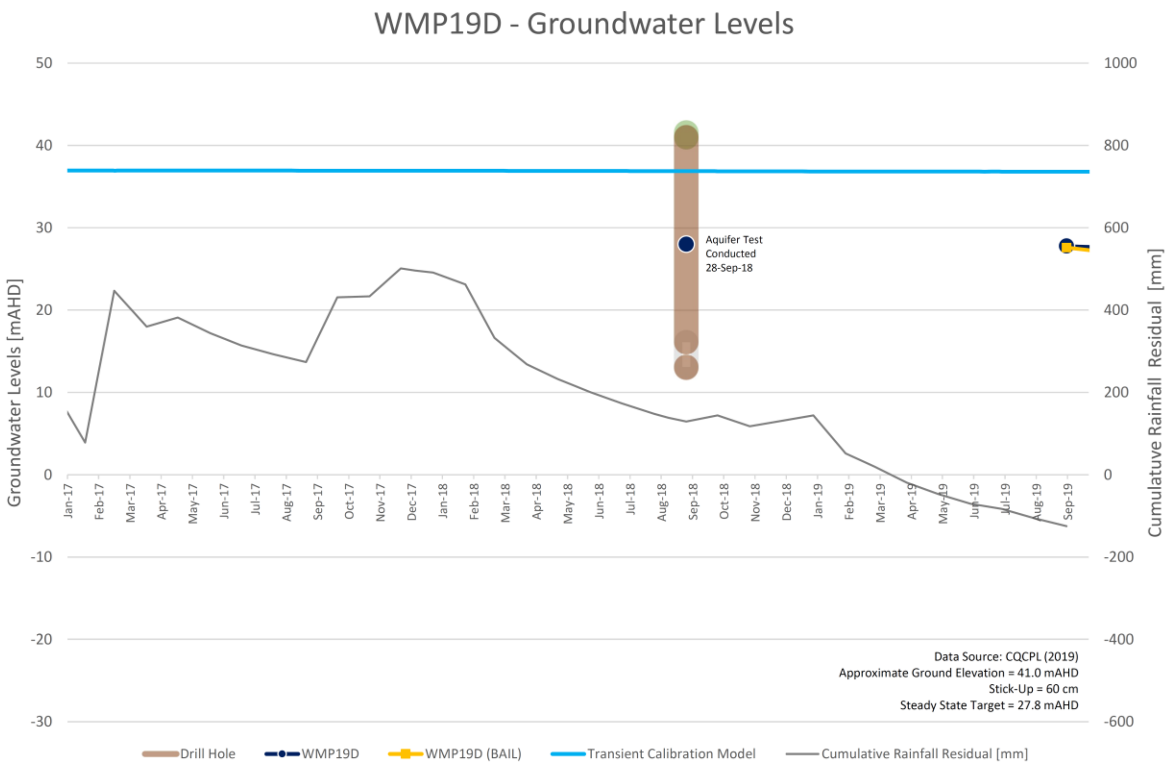
Graph A8-45: Permian Measures –
Back Creek Group
[WMP16]



Graph A8-46: Permian Measures – Back Creek Group [WMP16D]

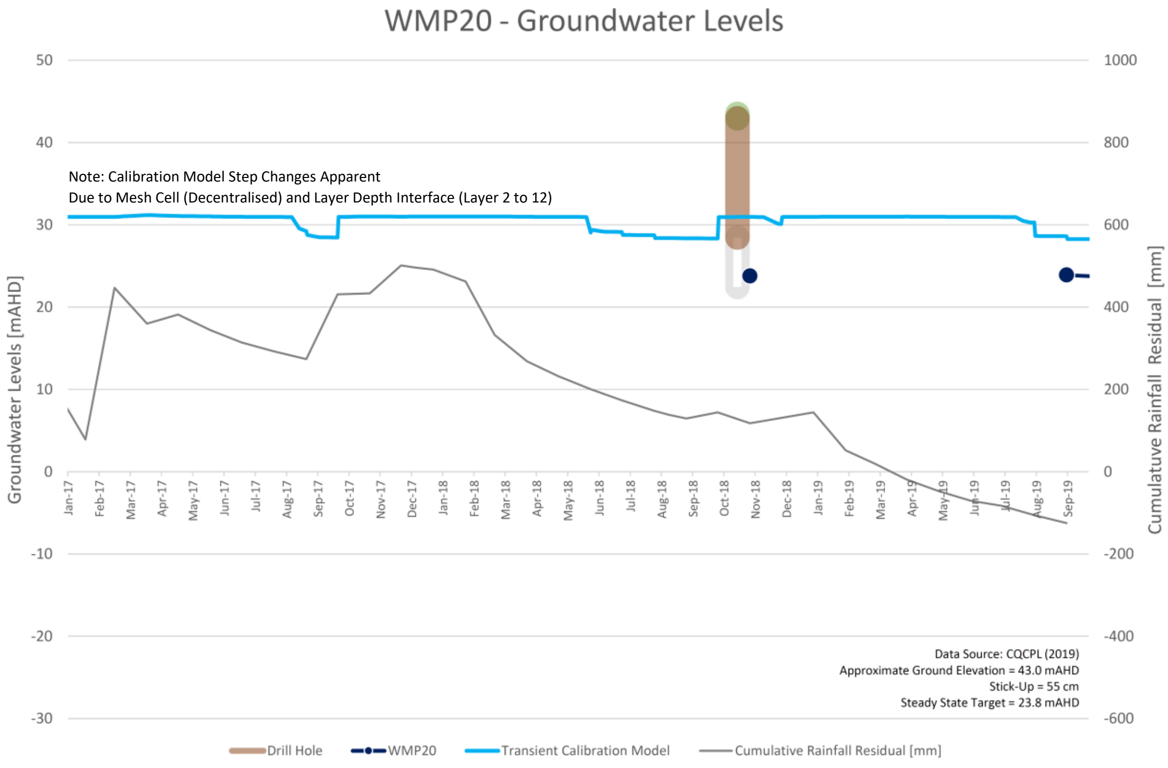


Graph A8-47: Permian Measures – Back Creek Group [WMP19]



Data Source: CQCPL (2019)
Approximate Ground Elevation = 41.0 mAHD
Stick-Up = 60 cm
Steady State Target = 27.8 mAHD

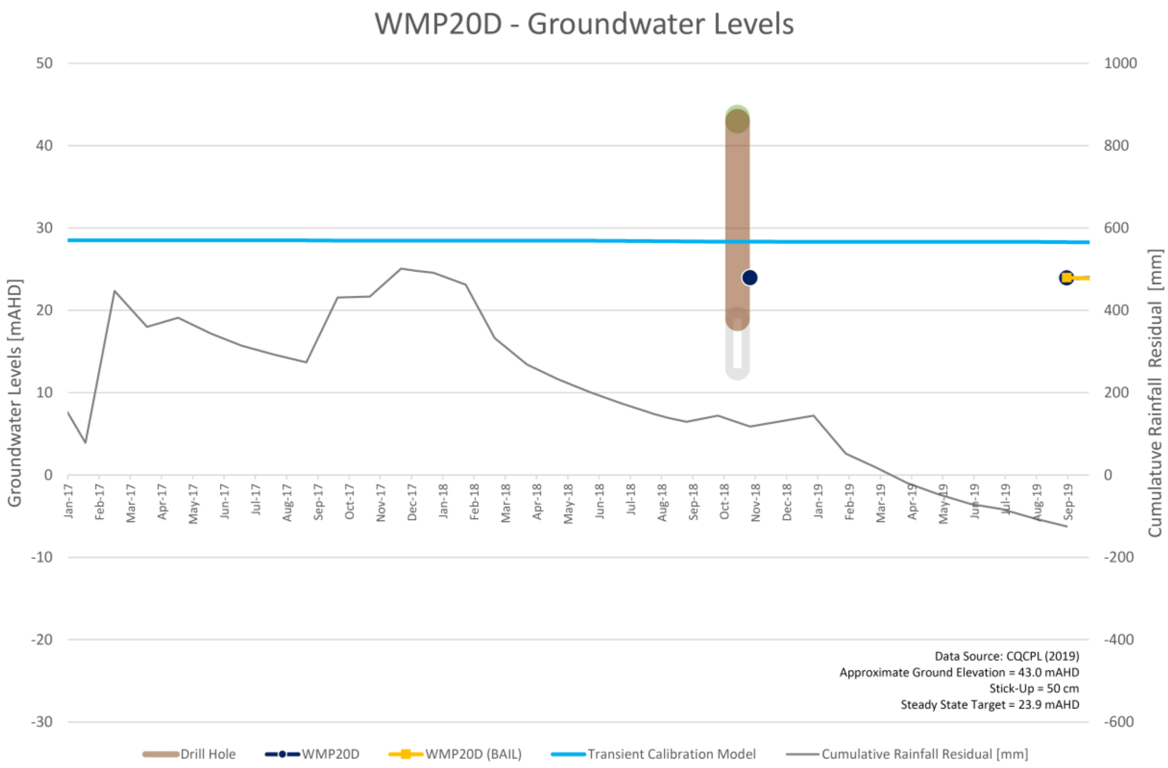
*Graph A8-48: Permian Measures –
Back Creek Group
[WMP19D]*



Note: Calibration Model Step Changes Apparent
Due to Mesh Cell (Decentralised) and Layer Depth Interface (Layer 2 to 12)

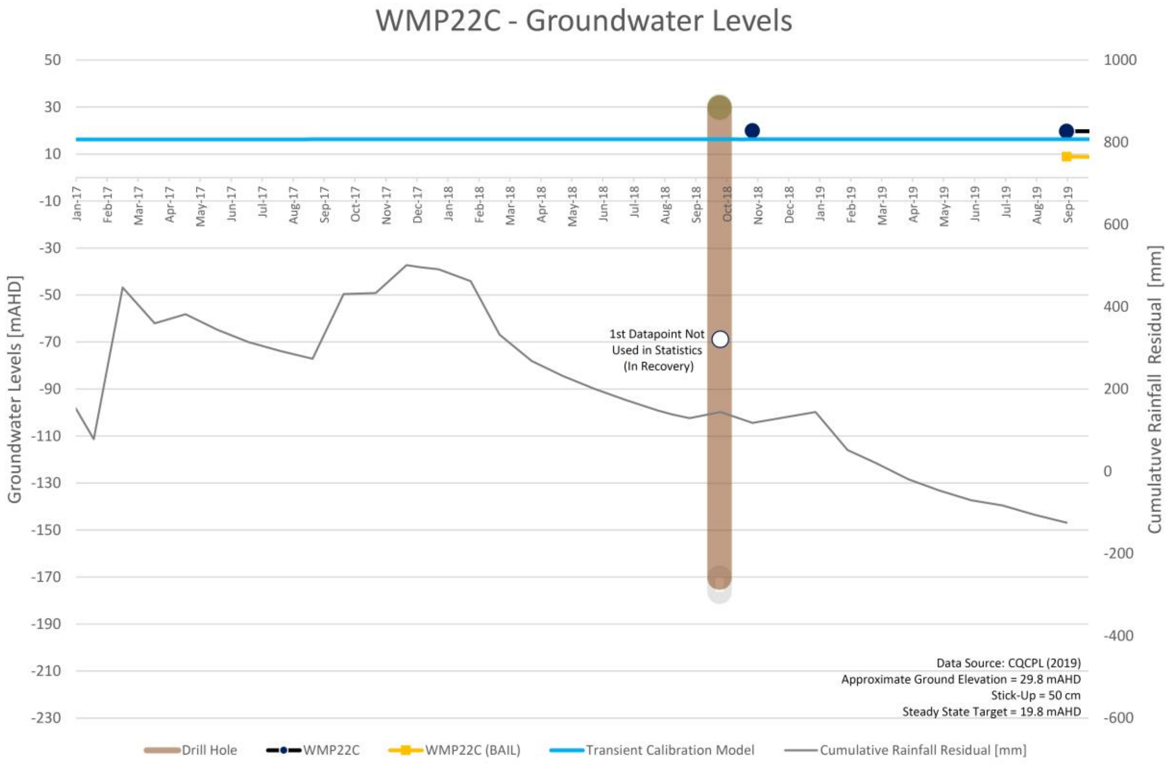
Data Source: CQCPL (2019)
Approximate Ground Elevation = 43.0 mAHD
Stick-Up = 55 cm
Steady State Target = 23.8 mAHD

*Graph A8-49: Permian Measures –
Back Creek Group
[WMP20]*



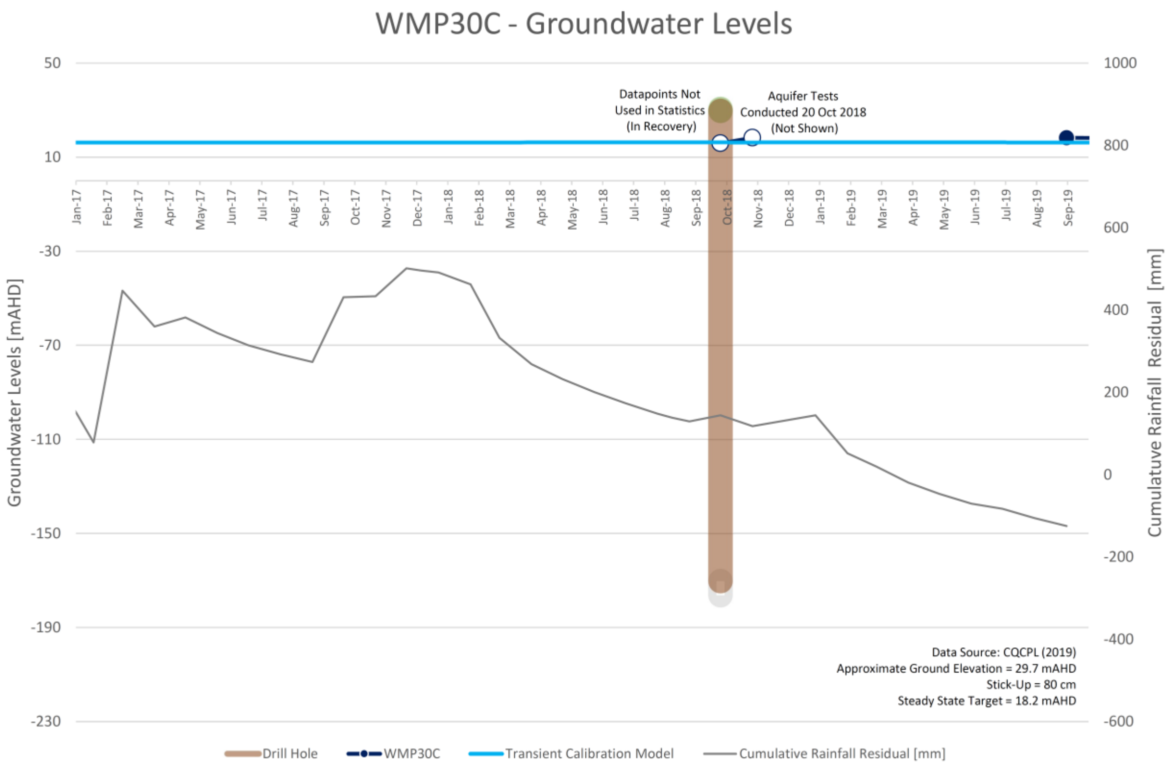
Data Source: CQCPL (2019)
Approximate Ground Elevation = 43.0 mAHD
Stick-Up = 50 cm
Steady State Target = 23.9 mAHD

Graph A8-50: Permian Measures – Back Creek Group [WMP20D]

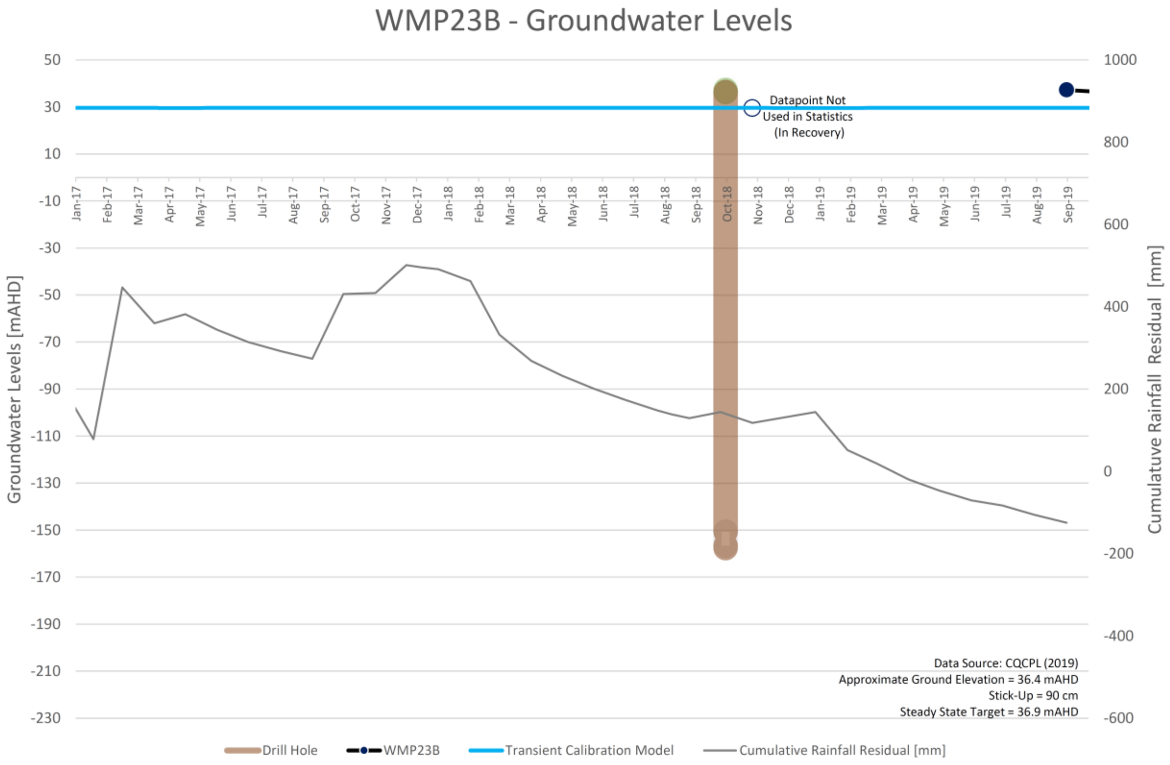


Data Source: CQCPL (2019)
Approximate Ground Elevation = 29.8 mAHD
Stick-Up = 50 cm
Steady State Target = 19.8 mAHD

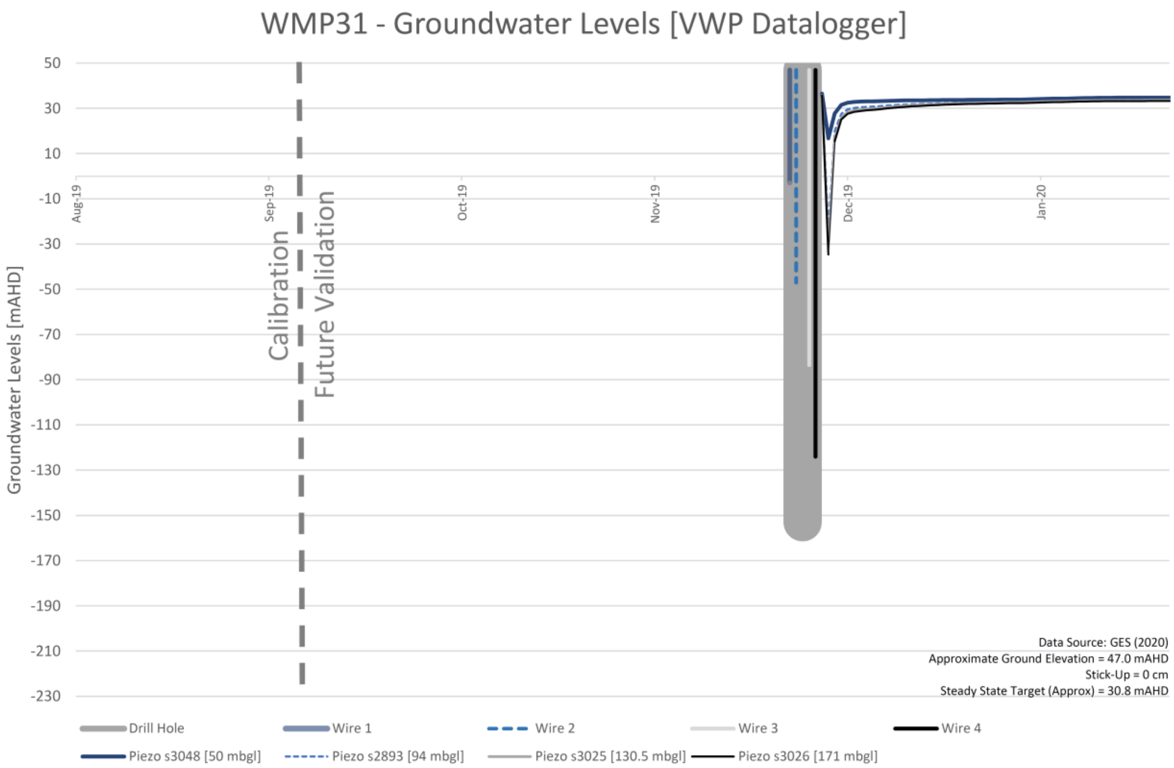
Graph A8-51: Permian Measures – Back Creek Group [WMP22C]



Graph A8-52: Permian Measures – Back Creek Group [WMP30C]



Graph A8-53: Permian Measures – Carmila Beds (and/or Back Creek Group) [WMP23B]



Graph A8-54: Permian Measures – Back Creek Group [WMP31]

ATTACHMENT 9
LABORATORY CORE PERMEABILITY AND POROSITY TESTWORK RESULTS (GES, 2020)

Groundwater Exploration Services
Pty Ltd
ABN 22 150 946 615
1/156 Arden Street,
Coogee NSW 2034
Tel +61 2 96649782
andyfulton@gmail.com

26th February 2020

John Bernal
Waratah Coal Pty Ltd
Level 17, 240 Queen Street
Brisbane QLD 4000

Attention: John

Re: Styx Core Test Data Results

Two recently drill holes were sampled to gain representative lithologies from major interburden units. Boreholes from which core samples were taken include STX1812 and STX1903. The core samples were laboratory tested to determine vertical and horizontal hydraulic conductivity. Testing for vertical permeability was taken perpendicular to the bedding planes, while horizontal permeability was taken parallel to the bedding planes. There was a high degree of test failures during the testing process under the pressurised test regimen which was predominantly occurred in laminated mudstone lithology while sand dominant intervals were better capable of standing up to pressures exerted. Of a total of 76 horizontal and vertical tests undertaken, 26 tests failed. This effectively skews the test data towards a higher value of permeability and porosity.

A summary of the core permeability test results is provided in Table 1. These results can be regarded as lower limits for use in model calibration, as cores do not capture the bulk fractured characteristics of a formation.

Porosity testing was also undertaken on a sub sample of the stratigraphic column presented by the two boreholes. Tis included 8 tests for total porosity and effective porosity or specific yield. Average total porosity was 9.7% and effective porosity was 1.1%.

Table 1: Core Permeability Test Results

Horizontal Hydraulic Conductivity (m/d)					
Arithmetic Mean	Harmonic Mean	Number of Samples	Max	Min	Formation
4.3×10^{-3}	9.1×10^{-5}	6	2.3×10^{-2}	1.4×10^{-6}	Regolith to Red Lower
1.9×10^{-5}	5.0×10^{-7}	15	1.2×10^{-4}	8.3×10^{-8}	Red Lower to Blue Lower
2.2×10^{-5}	4.4×10^{-6}	2	4.2×10^{-5}	2.3×10^{-6}	Blue Lower to Violet Lower

Vertical Hydraulic Conductivity (m/d)					
Arithmetic Mean	Harmonic Mean	Number of Samples	Max	Min	
9.2×10^{-4}	5.7×10^{-5}	7	3.2×10^{-3}	2.0×10^{-5}	Regolith to Red Lower
3.6×10^{-5}	4.8×10^{-7}	17	6.0×10^{-4}	8.3×10^{-8}	Red Lower to Blue Lower
1.4×10^{-6}	6.7×10^{-7}	3	3.1×10^{-6}	6.7×10^{-7}	Blue Lower to Violet Lower

Yours Sincerely

Andrew Fulton

ATTACHMENT 10
NUMERICAL GROUNDWATER MODEL REVIEW OF CONFIDENCE LEVEL CLASSIFICATION

Table A10-1
Numerical Groundwater Model Review of Confidence Level Classification – Characteristics and Indicators (Source: After Table 2-1 in Barnett *et al*. 2012): Data

Class 3	*Spatial and temporal distribution of groundwater head observations adequately define groundwater behaviour, especially in areas of greatest interest and where outcomes are to be reported.*	✓	Adequate Coverage [Refer Section 5.0, Attachments 4 and 8, Figures 5-3 & 5-4 and additional WMP31 (Graph A8-54)]
Class 3	*Spatial distribution of bore logs and associated stratigraphic interpretations clearly define aquifer geometry.*	~	Spatial Distribution in Styx Coal Measures Well-Defined, Cenozoic Sediments Site-Specific Delineation (TEM survey) [*Back Creek Group / Boomer Formation geometry less defined and based on 100k scale map*]
Class 3	*Good quality and adequate spatial coverage of digital elevation model to define groundwater surface elevation.*	✓	Combination of DEM (utilising LiDAR Data) Available for Tenements and Northern Areas (Figure 3-4)
Class 2	*Groundwater head observation and bore logs are available but may not provide adequate coverage through the model domain.*	✓	Adequate Coverage (Class 3 as above)
Class 1	*Few of poorly distributed existing wells from which to obtain reliable groundwater and geological information.*	~	N/A
Class 1	*Observations and measurements unavailable or sparsely distributed in areas of greatest interest.*	~	N/A
Class 3	*Aquifer-testing data to define key parameters.*	✓	Aquifer Testing Data Available [Section 5.6]
Class 3	*Reliable metered groundwater extraction and injection data is available.*	×	N/A
Class 2	*Metered groundwater-extraction data may be available but spatial and temporal coverage may not be extensive.*	✓	Aquifer Testing Data Available [Section 5.6]
Class 1	*No available records of metered groundwater extraction or injection*	~	N/A
Class 3	*Rainfall and evaporation data is available.*	✓	BOM Data / Mamelon Station Data [Section 3.1]
Class 1	*Climate data only available from relatively remote locations.*	~	N/A
Class 3	*Streamflow and stage measurements are available with reliable baseflow estimates at a number of points.*	×	Gauging Stations installed on Tooloombah Creek and Deep Creek
Class 2	*Streamflow data and baseflow estimates available at a few points.*	✓	FDC, Dry Records (no baseflow) and Tooloombah and Deep Creeks Stage Estimates and Ogmore Road Bridge & Validation (Section 7.8)
Class 1	*Little or no useful data on river flows and stage elevations.*	~	N/A
Class 3	*Reliable land-use and soil mapping data available.*	✓	Land Use Information is available [Section 3.4] Soil Mapping Data is available [Section 4.4]
Class 3	*Reliable irrigation application data (where relevant) is available.*	~	N/A
Class 2	*Reliable irrigation-application data available in part of the area or for part of the model duration.*	✓	Groundwater is not currently used for irrigation on the Mamelon property. No known irrigation bores.
Class 1	*Little or no useful data on land-use or soils.*	~	N/A

Target Confidence Level Achieved (Full and/or Partial)

Target Confidence Level Exceeded

Target Confidence Level Not Applicable

Table A10-2

Numerical Groundwater Model Review of Confidence Level Classification – Characteristics and Indicators (Source: After Table 2-1 in Barnett et al. 2012): Calibration

Class 3	*Adequate validation is demonstrated.*	✓	Sections 7.7 & 7.8 (& Historic Workings)
Class 2	*Validation is either not undertaken or is not demonstrated for the full model domain.*	✓	
Class 1	*No calibration is possible.*	×	N/A
Class 3	*Scaled RMS (SRMS) error or other calibration statistics (mass balance closure [MBC] error) are acceptable.*	✓	SRMS Error <10% MBC Error <0.5%
Class 2	*Calibration statistics are generally reasonable but may suggest significant errors in parts of the model domain(s).*	✓	
Class 1	*Calibration illustrates unacceptable levels of error especially in key areas.*	×	N/A
Class 3	*Long-term trends are adequately replicated where these are important.*	✓	Section 7.7.4 (Graph 7-3) [& Recognises Long-Term Below Average Rainfall Conditions] (Attachment 8)
Class 3	*Seasonal fluctuations are adequately replicated where these are important.*	-	
Class 2	*Long-term trends not replicated in all parts of the model domain.*	✓	
Class 2	*Season fluctuations not adequately replicated in all parts of the model domain.*	✓	
Class 1	*Calibration only to datasets other than that required for prediction.*	×	N/A
Class 3	*Transient calibration is current i.e. uses recent data.*	✓	Section 7.7 [2010 to Q3 2019] & 2020 Validation (Section 7.8)
Class 2	*Transient calibration to historic data but not extending to the present day.*	✓	
Class 1	*Calibration only to datasets other than that required for prediction.*	×	N/A
Class 3	*Model is calibrated to heads and fluxes.*	-	Sections 7.7 & 7.8 (Post Calibration Validation)
Class 3	*Observations of the key modelling outcomes dataset is used in calibration.*	-	
Class 2	*Observations of the key modelling outcomes dataset is not used in calibration.*	✓	
Class 1	*Calibration is based on an inadequate distribution of data*	×	N/A

Target Confidence Level Achieved (Full and/or Partial)

Target Confidence Level Exceeded

Target Confidence Level Not Applicable

Table A10-3
Numerical Groundwater Model Review of Confidence Level Classification – Characteristics and Indicators (Source: After Table 2-1 in Barnett *et al*. 2012): Prediction

Class 3	*Length of predictive model is not excessive compared to length of calibration period.*	-	Note Pre-calibration period
Class 2	*Transient calibration over a short time frame compared to that of prediction.*	✓	Sections 7.6 & 7.7 (Transient Calibration, Prediction & Recovery)
Class 1	*Predictive model timeframe far exceeds that of calibration.*	×	N/A
Class 3	*Temporal discretisation used in the predictive model is consistent with the transient calibration.*	-	N/A
Class 2	*Temporal discretisation used in the predictive model is different from that used in the transient calibration.*	✓	Section 7.6 (Monthly - Annual Stress Periods)
Class 1	*Temporal discretisation is different to that of calibration.*	×	N/A
Class 3	*Level and type of stresses included in the predictive model are within the range of those used in the transient calibration.*	-	N/A
Class 2	*Level and type of stresses included in the predictive model are outside the range of those used in the transient calibration.*	✓	Historic Mining Stresses applied in Pre-Calibration Only
Class 1	*Transient predictions are made when calibration is in steady state only.*	×	N/A
Class 3	*Model validation suggests calibration is appropriate for locations and/or times outside the calibration period.*	✓	Sections 7.7.4 & 7.8 [Pre-Calibration, Pools & VWP31]
Class 2	*Validation suggests relatively poor match to observations when calibration data is extended in time and/or space.*	-	N/A
Class 1	*Model validation suggests unacceptable errors when calibration dataset is extended in time and/or space.*	×	N/A
Class 3	*Steady-state predictions used when the model is calibrated in steady-state only.*	-	N/A

Target Confidence Level Achieved (Full and/or Partial)

Target Confidence Level Exceeded

Target Confidence Level Not Applicable

Table A10-4
Numerical Groundwater Model Review of Confidence Level Classification – Characteristics and Indicators (Source: After Table 2-1 in Barnett *et al*. 2012): Key Indicator

Class 3	*Key calibration statistics are acceptable and meet agreed targets.*	✓	SRMS <10% MBC <0.5%
Class 2	*Key calibration statistics suggest poor calibration in parts of the model domain.*	×	N/A
Class 1	*Model is uncalibrated or key calibration statistics do not meet agreed targets.*	×	N/A
Class 3	*Model predictive time frame is less than 3 times the duration of transient calibration.*	-	Section 7.6 [2010-2017/2019] [2020-2038]
Class 2	*Model predictive time frame is between 3 and 10 times the duration of transient calibration.*	✓	
Class 1	*Model predictive time frame is more than 10 times longer than transient calibration period.*	×	N/A
Class 3	*Stresses are not more than 2 times greater than those included in calibration.*	-	Section 7.7.4 (NB: Historic Workings)
Class 2	*Stresses are between 2 and 5 times greater than those included in calibration.*	✓	
Class 1	*Stresses are more than 5 times greater than those in calibration.*	×	N/A
Class 3	*Temporal discretisation in predictive model is the same as that used in calibration.*	-	Section 7.6.2 (Monthly - Annual Stress Periods)
Class 2	*Temporal discretisation in predictive model is not the same as that used in calibration.*	✓	
Class 1	*Stress period or calculation interval is different from that used in calibration.*	×	N/A
Class 1	*Transient predictions made but calibration in steady state only.*	×	N/A
Class 3	*Mass balance closure error is less than 0.5% of total.*	✓	MBC Error <0.5%
Class 2	*Mass balance closure error is less than 1% of total.*	✓	
Class 1	*Cumulative mass-balance closure error exceeds 1% or exceeds 5% at any given calculation time.*	×	N/A
Class 3	*Model parameters consistent with conceptualisation.*	-	Section 7.7 (Calibrated Parameters Used)
Class 2	*Not all model parameters consistent with conceptualisation.*	✓	
Class 1	*Model parameters outside the range expected by conceptualisation with no further justification.*	×	N/A
Class 3	*Appropriate computational methods used with appropriate spatial discretisation to model the problem.*	✓	MODFLOW-USG, AlgoMesh, USG-Transport
Class 2	*Spatial refinement too coarse in key parts of the model domain.*	-	N/A
Class 1	*Unsuitable spatial or temporal discretisation.*	×	N/A
Class 3	*The model has been reviewed and deemed fit for purpose by an experienced, independent hydrogeologist with modelling experience.*	✓	Staged Peer Review by AGE Consultants [*Refer to Final Letter*]
Class 2	*The model has been reviewed and deemed fit for purpose by an independent hydrogeologist.*	✓	
Class 1	*The model has not been reviewed.*	-	

Target Confidence Level Achieved (Full and/or Partial)

Target Confidence Level Exceeded

Target Confidence Level Not Applicable

Table A10-5

Numerical Groundwater Model Review of Confidence Level Classification – Characteristics and Indicators (Source: After Table 2-1 in Barnett *et al*. 2012): Examples of Specific Uses

Class 3	*Provide information for sustainable yield assessments for high-value regional aquifer systems.*	-	Not Required
Class 3	*Assessment of complex, large scale solute transport processes.*	-	Model Capable with Potential Opportunities to Refine in Future Updates
Class 3	*Can be used to design complex mine-dewatering schemes, salt-interception schemes or water allocation plans.*	-	
Class 3	*Simulating the interaction between groundwater and surface water bodies to level of reliability required for dynamic linkage to surface water models.*	-	
Class 3	*Suitable for predicting groundwater responses to arbitrary changes in applied stress or hydrological conditions anywhere within the model domain.*	-	
Class 3	*Evaluation and management of potentially high-risk impacts.*	-	
Class 2	*Designing groundwater management scheme such as managed aquifer recharge, salinity management schemes and infiltrations basins.*	-	
Class 2	*Defining water source protection zones.*	-	
Class 2	*Estimating distance of travel of contamination through particle-tracking methods.*	✓	Model Capable
Class 2	*Prediction of impacts of proposed developments in medium value aquifers.*	✓	Model Capable - Aquifers of Limited Potential
Class 2	*Providing estimates of dewatering requirements for mines and excavations and the associated impacts.*	✓	Model Capable - Mine Inflows Estimated and Impacts Assessed
Class 2	*Evaluation and management of medium risk impacts.*	✓	
Class 1	*Predicting long-term impacts of proposed developments in low-value aquifers.*	✓	Model Capable
Class 1	*Estimating impacts of low-risk developments.*	✓	Model Capable
Class 1	*Design observation bore array for pumping tests.*	✓	Model Capable
Class 1	*Understanding groundwater flow processes under various hypothetical conditions.*	✓	Model Capable
Class 1	*Provide first-pass estimates of extraction volumes and rates required for mine dewatering.*	✓	Model Capable
Class 1	*Develop coarse relationships between groundwater extraction locations and rates and associated impacts.*	✓	Model Capable
Class 1	*As a starting point on which to develop higher class models as more data is collected and used.*	✓	Model Capable

Target Confidence Level Achieved

Model Capable

Model Capable
With Potential Limitations

ATTACHMENT 11
UNCERTAINTY ANALYSIS OUTPUTS [HYDROALGORITHMICS, 2020]

Uncertainty Analysis

Methodology

This study addresses parameter uncertainty by stochastic modelling using the *Latin Hypercube Sampling (LHS)* method: generating numerous alternative parameterisations of the deterministic flow model (realisations), executing the model independently for each, and then aggregating the results for statistical analysis. LHS is similar to the classical *Monte Carlo* method but uses a stratified sampling technique, which typically provides faster convergence.

A traditional drawback to the Monte Carlo and LHS methods is that their successful application often necessitates hundreds or thousands of model runs, each of which may take several hours of run time on a modern computer. More complex variants of Monte Carlo exist which aim to explore the parameter space more efficiently than the basic Monte Carlo approach, such as Null Space Monte Carlo (NSMC) (*Doherty, 2015*) and Markov Chain Monte Carlo (MCMC) approaches (e.g. *Vrugt et al., 2009*).

However, recent offerings in the field of cloud computing have greatly increased the availability and accessibility of computing resources, allowing hundreds of model runs to be evaluated simultaneously. Owing to this, we have elected to use the LHS approach, which places no reliance on a linearisation of the model, allows for each individual model run to be kept relatively simple and with predictable run time (no additional calibration steps), and is free from the problem of autocorrelated samples that may occur with MCMC approaches.

AlgoCompute (*HydroAlgorithmics, 2019*; *Merrick, 2017*) was used as the platform for executing the model runs in parallel; up to 100 realisations were evaluated simultaneously, each being allocated to a single virtual machine in the cloud. The model-independent uncertainty quantification software HGSUQ (*Miller et al., 2018*) was used to generate the LHS parameter realisations and orchestrate the model runs within the AlgoCompute environment.

Parameters

Uncertainty was assessed on hydraulic conductivity, infiltration rates, specific storage and specific yield properties throughout the model. The pilot points used for the parameterisation of the calibrated model in layers 2 to 14 were retained, with a parameter for each hydraulic property at each pilot point, allowing for spatial variation in property values. Model layer 1 was used only for final landform emplacements and its hydraulic properties were not altered for this uncertainty analysis.

A “prior” statistical distribution was assigned to each parameter based on the calibrated model values, from which randomly-sampled values were generated for each evaluated model realisation – subsequently interpolated to model cells by *kriging*.

All parameters were assigned log-normal distributions with mean at the calibrated model value. As was the case in model calibration, infiltration rates were represented as ratios on lateral hydraulic conductivity (Kx ÷ (fractional infiltration rate)), henceforth named KxInfil parameters. Vertical hydraulic conductivities (Kz) were represented as anisotropy ratios (Kx ÷ Kz), named KxKz.

A log standard deviation of 0.5 was applied for the prior distributions of Kx, KxKz, KxInfil and specific storage (Ss) parameters, such that 95% of randomly sampled values should lie within one order of magnitude (two standard deviations) either side of the calibrated parameter values.

For specific yield (Sy), a lower standard deviation of 0.25 was used to ensure a physically reasonable 95% range of values (half an order of magnitude either side of the calibrated values). KxKz parameters were assigned a truncated log-normal distribution to ensure a lower bound of 1 on vertical anisotropy (Kz ≤ Kx).

Run procedure

For each LHS realisation, the following procedure was executed on a virtual machine in the cloud, initiated by a HGSUQ worker process:

1. Interpolate pilot point parameter values to model cells and produce corresponding data files for inclusion in model LPF and RCH packages.
2. Run steady-state model to establish initial model heads.
3. Run transient model with proposed CQC mining *active* (*impacted* case).
4. Run transient model with proposed CQC mining *inactive* (*baseline* case).
5. Process model result files to compute calibration statistics and predictive outputs (impacted minus baseline: drawdown, mine inflow, flow impacts) and return these to the HGSUQ "master" process for amalgamation with other run results.

Assumptions

The following assumptions should be noted in assessing the information presented in this uncertainty analysis.

- The stochastic modelling performed was limited to the parameters described in the *Parameters* section of this document. Uncertainty was not assessed on any other aspects of the model.
- Spatial variability was assessed only to the resolution of the pilot point set, and within the limits of the delineated property zones.
- Each calibrated realisation was assumed to be equally likely in the analysis of the model outputs, i.e. apart from rejecting particularly poorly-calibrated runs, no weighting was applied to distinguish models based on how well they fit the observed data.

Parameter Distributions

Two sets of parameter distributions are discussed in this section: *prior* and *posterior* distributions. The prior distributions are those from which the LHS process builds random samples for evaluation. The LHS process produces a finite number of sample sets (realisations). Additionally, some of these realisations are rejected during evaluation due to non-convergence or poor calibration. The posterior distributions represent the actual property distributions evaluated after sampling and rejection have taken place.

In total, 1,000 realisations were evaluated as part of the LHS process. A calibration constraint on the scaled root-mean square (SRMS) error was applied such that any model with an SRMS of more than 3% was rejected. Of the 1,000 realisations, 602 (60.2%) were accepted, 5 were rejected due to non-convergence (0.5%) and 393 (39.3%) were rejected because they exceeded the prescribed calibration constraint.

Prior and posterior distributions

Substantial differences between the posterior and prior distributions may indicate that part of the prior distribution resulted in poorly-calibrated or non-convergent models. Table 1 compares the mean and standard deviation (*stdev*) of prior and posterior distributions for all Kx parameters, aggregated over all pilot points in each zone. Posterior-prior differences are calculated as the absolute value of the difference between the two relevant posterior and prior values (mean or log stdev), divided by the average of the two values, then converted to a percentage.

Table 2 through Table 5 similarly compare prior and posterior distributions for KxKz, KxInfil, Ss and Sy parameters.

Note that the prior mean and standard deviation values reported here are each an aggregation across all pilot points in each zone. These values were obtained by computing mean and standard deviations of aggregate distributions as a sum of independent random variables. By this formulation, aggregate mean values are calculated as the mean of individual means for all pilot points in their respective zones. Aggregate standard deviations are the square root of the aggregate variances, which are calculated as the mean of individual variances of all pilot points in the zone plus the variance of means of all pilot points in the zone.

This aggregation allows a high-level comparison between prior and posterior to be made which accounts for the different mean values among pilot points as derived from calibrated model values, as well as differences in standard deviations among pilot point distributions as a result of truncated distributions being used (in the case of KxKz parameters).

Comparisons of means and standard deviations in the tables suggest very little difference between prior and posterior distributions, with most differences well below 1.0% and a maximum difference of 2.1%.

Table 1: Summary statistics of posterior vs prior lateral hydraulic conductivity (Kx) distributions.
Note that mean values are non log-transformed.

			Posterior Kx		Prior Kx		Posterior-Prior Kx Difference	
Layer	Zone	Lithology	Mean	Log Stdev	Mean	Log Stdev	Mean	Log Stdev
2	21	Regolith / Weathered Kx, Pb, Pbm, Pc	4.0E+00	0.50	4.0E+00	0.50	0.8%	0.1%
	22	Qa, Qhe/s, Qhe/m, Qhcm	2.0E+01	0.50	2.0E+01	0.50	0.3%	0.1%
	23	Qpa, Qr, Qf > Kx	4.1E+00	0.50	4.1E+00	0.50	0.6%	0.1%
	24	TQr, Ta, Td	5.2E-01	0.56	5.2E-01	0.56	0.7%	0.1%
3	31	Regolith / Weathered Kx, Pb, Pbm, Pc	4.0E+00	0.50	4.0E+00	0.50	0.6%	0.6%
	32	Qa, Qhe/s, Qhe/m, Qhcm	5.0E+00	0.57	5.0E+00	0.57	0.1%	0.2%
	33	Qpa, Qr, Qf > Kx	1.7E+00	0.65	1.7E+00	0.64	0.1%	0.2%
	34	TQr, Ta, Td	2.5E-01	0.50	2.5E-01	0.50	1.1%	0.5%
4	4	Regolith / Weathered Kx, Pb, Pbm, Pc, Cp	7.9E-01	0.67	7.9E-01	0.67	0.4%	0.2%
5	5	Styx Coal Measures (Overburden / Interburden – Upper)	2.0E-01	0.50	2.0E-01	0.50	0.4%	0.1%
6	6	Coal (G1-R Lower Aggregate)	1.7E-01	0.59	1.7E-01	0.59	0.5%	0.1%
7	7	Styx Coal Measures (Interburden – Mid)	3.0E-02	0.50	3.0E-02	0.50	0.2%	0.0%
8	8	Coal (P-B Lower 2 Aggregate)	1.1E-02	0.70	1.1E-02	0.70	0.1%	0.3%
9	9	Styx Coal Measures (Interburden – Lower)	1.3E-03	0.56	1.3E-03	0.56	0.2%	0.1%
10	10	Coal (V Upper 1-V Lower 2 Aggregate)	4.9E-02	0.81	4.9E-02	0.81	0.1%	0.0%
11	11	Styx Coal Measures (Underburden)	5.6E-03	0.64	5.6E-03	0.64	0.6%	0.1%
12	121	Back Creek Group / Boomer Formation	4.0E-04	0.50	4.0E-04	0.50	0.1%	0.3%
	122	Glenprairie / Wangrabry Beds	4.0E-03	0.50	4.0E-03	0.50	0.6%	0.2%
13	13	Lizzie Creek Volcanic Group / Carmila Beds	1.2E-04	0.64	1.2E-04	0.64	0.1%	0.2%
14	14	Intrusive Rocks / Connors Volcanic Group	1.0E-06	0.50	1.0E-06	0.50	0.4%	0.1%

Table 2: Summary statistics of posterior vs prior vertical anisotropy (KxKz) distributions. Note that mean values are non log-transformed.

			Posterior KxKz		Prior KxKz		Posterior-Prior KxKz Difference	
Layer	Zone	Lithology	Mean	Log Stdev	Mean	Log Stdev	Mean	Log Stdev
2	21	Regolith / Weathered Kx, Pb, Pbm, Pc	6.4	0.44	6.4	0.44	0.4%	0.0%
	22	Qa, Qhe/s, Qhe/m, Qhcm	25.6	0.50	25.6	0.51	0.0%	0.2%
	23	Qpa, Qr, Qf > Kx	3.9	0.39	3.9	0.39	0.0%	0.1%
	24	TQr, Ta, Td	16.9	0.50	16.8	0.50	0.6%	0.1%
3	31	Regolith / Weathered Kx, Pb, Pbm, Pc	12.4	0.48	12.3	0.48	0.5%	0.0%
	32	Qa, Qhe/s, Qhe/m, Qhcm	226.0	0.51	225.6	0.51	0.2%	0.0%
	33	Qpa, Qr, Qf > Kx	17.9	0.50	17.9	0.50	0.2%	0.2%
	34	TQr, Ta, Td	12.2	0.47	12.1	0.48	0.4%	0.4%
4	4	Regolith / Weathered Kx, Pb, Pbm, Pc, Cp	110.6	0.52	110.4	0.52	0.1%	0.2%
5	5	Styx Coal Measures (Overburden / Interburden – Upper)	99.4	0.55	99.4	0.55	0.1%	0.1%
6	6	Coal (G1-R Lower Aggregate)	6.8	0.45	6.8	0.45	0.1%	0.2%
7	7	Styx Coal Measures (Interburden – Mid)	20.4	0.56	20.4	0.56	0.0%	0.5%
8	8	Coal (P-B Lower 2 Aggregate)	6.4	0.44	6.3	0.44	0.5%	0.2%
9	9	Styx Coal Measures (Interburden – Lower)	24.4	0.57	24.3	0.57	0.4%	0.2%
10	10	Coal (V Upper 1-V Lower 2 Aggregate)	8.6	0.47	8.6	0.47	0.0%	0.1%
11	11	Styx Coal Measures (Underburden)	11.8	0.53	11.7	0.54	0.7%	0.2%
12	121	Back Creek Group / Boomer Formation	2.5	0.30	2.5	0.30	0.1%	0.1%
	122	Glenprairie / Wangrabry Beds	2.5	0.30	2.5	0.30	0.5%	0.4%
13	13	Lizzie Creek Volcanic Group / Carmila Beds	2.5	0.30	2.5	0.30	0.4%	0.5%
14	14	Intrusive Rocks / Connors Volcanic Group	2.5	0.30	2.5	0.30	0.1%	0.7%

Table 3: Summary statistics of posterior vs prior fractional infiltration ratio (KxInfil) distributions. Note that mean values are non log-transformed.

			Posterior KxInfil		Prior KxInfil		Posterior-Prior KxInfil Difference	
Layer	Zone	Lithology	Mean	Log Stdev	Mean	Log Stdev	Mean	Log Stdev
2	21	Regolith / Weathered Kx, Pb, Pbm, Pc	676.6	0.75	672.8	0.75	0.6%	0.6%
	22	Qa, Qhe/s, Qhe/m, Qhcm	2116.4	0.67	2112.5	0.67	0.2%	0.1%
	23	Qpa, Qr, Qf > Kx	1599.3	0.55	1587.5	0.55	0.7%	0.5%
	24	TQr, Ta, Td	31.2	0.57	31.6	0.57	1.3%	0.1%

Table 4: Summary statistics of posterior vs prior specific storage (Ss) distributions.
Note that mean values are non log-transformed.

			Posterior Ss		Prior Ss		Posterior-Prior Ss Difference	
Layer	Zone	Lithology	Mean	Log Stdev	Mean	Log Stdev	Mean	Log Stdev
2	21	Regolith / Weathered Kx, Pb, Pbm, Pc	1.3E-05	0.50	1.3E-05	0.50	0.1%	0.0%
	22	Qa, Qhe/s, Qhe/m, Qhcm	1.3E-05	0.50	1.3E-05	0.50	0.2%	0.0%
	23	Qpa, Qr, Qf > Kx	1.3E-05	0.50	1.3E-05	0.50	0.1%	0.3%
	24	TQr, Ta, Td	1.3E-05	0.50	1.3E-05	0.50	0.3%	0.3%
3	31	Regolith / Weathered Kx, Pb, Pbm, Pc	1.3E-05	0.50	1.3E-05	0.50	0.3%	0.1%
	32	Qa, Qhe/s, Qhe/m, Qhcm	1.3E-05	0.50	1.3E-05	0.50	0.0%	0.1%
	33	Qpa, Qr, Qf > Kx	1.3E-05	0.50	1.3E-05	0.50	0.2%	0.1%
	34	TQr, Ta, Td	1.3E-05	0.49	1.3E-05	0.50	1.5%	2.1%
4	4	Regolith / Weathered Kx, Pb, Pbm, Pc, Cp	1.3E-05	0.50	1.3E-05	0.50	0.4%	0.0%
5	5	Styx Coal Measures (Overburden / Interburden – Upper)	5.0E-06	0.52	5.0E-06	0.52	0.4%	0.1%
6	6	Coal (G1-R Lower Aggregate)	5.3E-06	0.51	5.3E-06	0.51	0.5%	0.2%
7	7	Styx Coal Measures (Interburden – Mid)	5.4E-06	0.52	5.3E-06	0.52	0.2%	0.0%
8	8	Coal (P-B Lower 2 Aggregate)	5.2E-06	0.52	5.2E-06	0.51	0.1%	0.2%
9	9	Styx Coal Measures (Interburden – Lower)	5.0E-06	0.51	5.0E-06	0.51	0.4%	0.0%
10	10	Coal (V Upper 1-V Lower 2 Aggregate)	5.0E-06	0.51	5.0E-06	0.51	0.3%	0.0%
11	11	Styx Coal Measures (Underburden)	5.3E-06	0.51	5.3E-06	0.51	0.4%	0.3%
12	121	Back Creek Group / Boomer Formation	4.8E-06	0.55	4.8E-06	0.54	0.5%	0.2%
	122	Glenprairie / Wangrabry Beds	3.3E-06	0.67	3.3E-06	0.67	0.2%	0.0%
13	13	Lizzie Creek Volcanic Group / Carmila Beds	5.1E-06	0.51	5.1E-06	0.51	0.1%	0.1%
14	14	Intrusive Rocks / Connors Volcanic Group	5.1E-06	0.51	5.0E-06	0.51	1.1%	0.2%

Table 5: Summary statistics of posterior vs prior specific yield (Sy) distributions.
Note that mean values are non log-transformed.

			Posterior Sy		Prior Sy		Posterior-Prior Sy Difference	
Layer	Zone	Lithology	Mean	Log Stdev	Mean	Log Stdev	Mean	Log Stdev
2	21	Regolith / Weathered Kx, Pb, Pbm, Pc	0.48%	0.32	0.48%	0.32	0.1%	0.2%
	22	Qa, Qhe/s, Qhe/m, Qhcm	1.94%	0.31	1.94%	0.31	0.0%	0.2%
	23	Qpa, Qr, Qf > Kx	1.00%	0.29	1.01%	0.29	0.0%	0.0%
	24	TQr, Ta, Td	1.05%	0.28	1.04%	0.28	0.0%	0.5%
3	31	Regolith / Weathered Kx, Pb, Pbm, Pc	0.49%	0.27	0.49%	0.27	0.1%	0.2%
	32	Qa, Qhe/s, Qhe/m, Qhcm	2.01%	0.27	2.01%	0.27	0.0%	0.3%
	33	Qpa, Qr, Qf > Kx	0.95%	0.35	0.95%	0.35	0.1%	0.2%
	34	TQr, Ta, Td	1.18%	0.25	1.17%	0.26	0.6%	1.3%
4	4	Regolith / Weathered Kx, Pb, Pbm, Pc, Cp	0.52%	0.33	0.52%	0.33	0.1%	0.3%
5	5	Styx Coal Measures (Overburden / Interburden – Upper)	0.52%	0.27	0.52%	0.27	0.1%	0.4%
6	6	Coal (G1-R Lower Aggregate)	0.52%	0.27	0.52%	0.27	0.0%	0.1%
7	7	Styx Coal Measures (Interburden – Mid)	0.51%	0.28	0.51%	0.28	0.0%	0.3%
8	8	Coal (P-B Lower 2 Aggregate)	0.53%	0.27	0.53%	0.27	0.1%	0.0%
9	9	Styx Coal Measures (Interburden – Lower)	0.53%	0.29	0.53%	0.30	0.0%	0.3%
10	10	Coal (V Upper 1-V Lower 2 Aggregate)	0.52%	0.27	0.52%	0.27	0.0%	0.2%
11	11	Styx Coal Measures (Underburden)	0.53%	0.28	0.53%	0.28	0.2%	0.0%
12	121	Back Creek Group / Boomer Formation	0.53%	0.28	0.53%	0.28	0.1%	0.1%
	122	Glenprairie / Wangrabry Beds	0.34%	0.44	0.34%	0.44	0.0%	0.1%
13	13	Lizzie Creek Volcanic Group / Carmila Beds	0.52%	0.27	0.52%	0.27	0.1%	0.2%
14	14	Intrusive Rocks / Connors Volcanic Group	0.46%	0.28	0.46%	0.28	0.2%	0.1%

Results

Statistics on key predictive outputs were computed from the results of the 602 accepted model runs and are presented in this section. Percentile results were calculated from the LHS outputs strictly on a conservative "round to higher value" basis, and are represented as "probabilities of exceedance" in five categories: "very likely (90%) - **green**, "likely (67%)" - **light yellow-green**, "about as likely as not (50%)" - **black**, "unlikely (33%)" - **orange**, and "very unlikely (10%)" - **red**.

To clarify, a "very unlikely (10%)" probability of exceedance value of X for a metric should be interpreted as "10% of realisations from the set of accepted realisations resulted in a value for this metric larger than X."

Drawdown and streamflow impact results were all computed on the difference between *impacted* and *baseline* scenarios. The impacted scenario simulated both historical mining and proposed CQC mining, whereas the baseline scenario simulated only historical mining.

Key predictive outputs

Table 6 presents probabilities of exceedance for mine inflows and streamflow impacts. The distribution of model calibration error is also shown for reference. All flows presented here are the maximum flow over time.

Note that each row of the table represents a different distribution of the LHS run results, wherein each percentile result is representative of a different subset of runs. As such, the results from different rows should be taken independently and may not be directly combined. For example, the set of runs for which calibration error was at most 2.79% does not necessarily correlate with the set of runs for which there was a peak combined mine inflow of 696.5 ML/year, despite these being presented in the same column of the table.

In the case of streamflow impacts, it should be noted that the peak values presented are exaggerated somewhat by the limited resolution of stress periods in the model, and the resulting spikes in groundwater flows; see the time series charts later in this section for an illustration of this. Nevertheless, these values remain conservative within the assumptions of the uncertainty analysis performed.

Table 6: Probability of exceedance of mine inflows, streamflow impacts, storage changes and the calibration error distribution.

	Very likely (90%)	Likely (67%)	About as likely as not (50%)	Unlikely (33%)	Very unlikely (10%)
Peak mine inflow (Combined) (ML/year)	404.4	579.0	696.5	848.3	1241.1
Peak mine inflow (North Pit) (ML/year)	357.7	514.3	631.9	784.2	1152.3
Peak mine inflow (South Pit) (ML/year)	121.7	189.4	223.2	278.4	401.5
Peak baseflow impact / enhanced leakage for Tooloombah Creek (ML/year)	259.5	329.0	367.7	415.9	530.1
Peak baseflow impact / enhanced leakage for Styx River (ML/year)	3.1	5.2	6.5	8.0	12.5
Peak baseflow impact / enhanced leakage for Deep Creek (ML/year)	168.6	281.6	342.0	411.1	625.5
Peak baseflow impact / enhanced leakage for Mamelon Creek (ML/year)	0.0	0.0	0.1	0.4	1.2
Peak storage change for FHA-047 (ML/year)	0.0	0.0	0.0	0.0	0.0
Calibration error (SRMS)	2.59%	2.73%	2.79%	2.86%	2.95%

Time series flows: mine inflow (combined)

Figure 1 shows mine inflow over time to both pits (combined) at 10%, 33%, 50%, 67% and 90% probabilities of exceedance. The time-series inflows are time-weighted averages over quarterly periods.

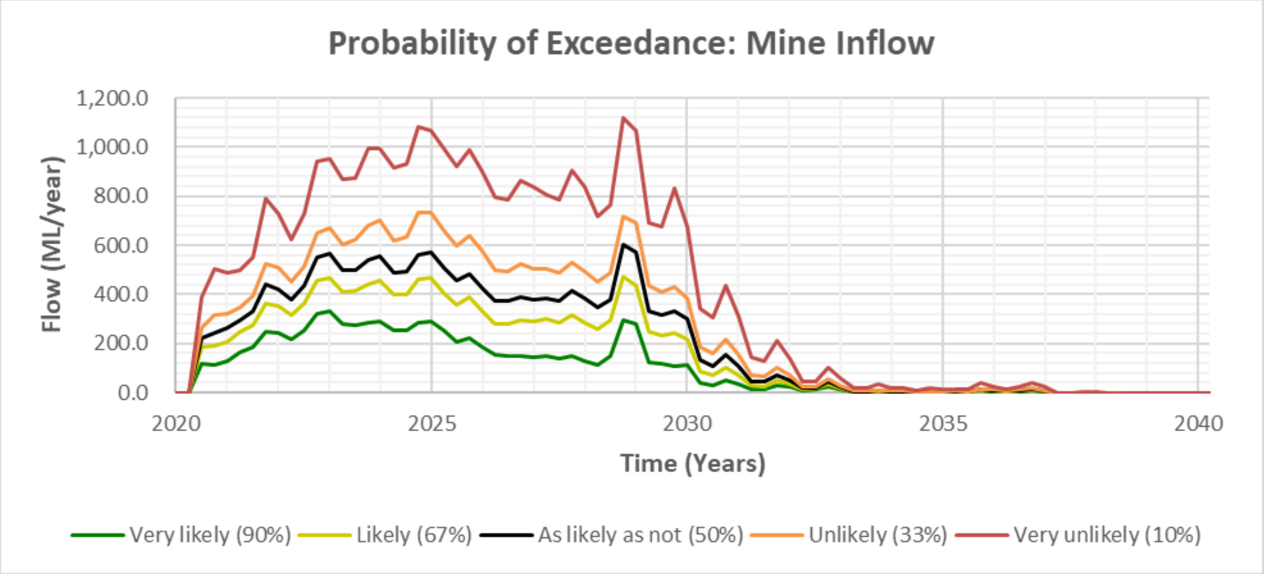


Figure 1: Time-series inflow to both pits (combined).

Time series flows: baseflow impact / enhanced leakage for Tooloombah Creek

Figure 2 shows baseflow impact / enhanced leakage over time to Tooloombah Creek at 10%, 33%, 50%, 67% and 90% probabilities of exceedance.

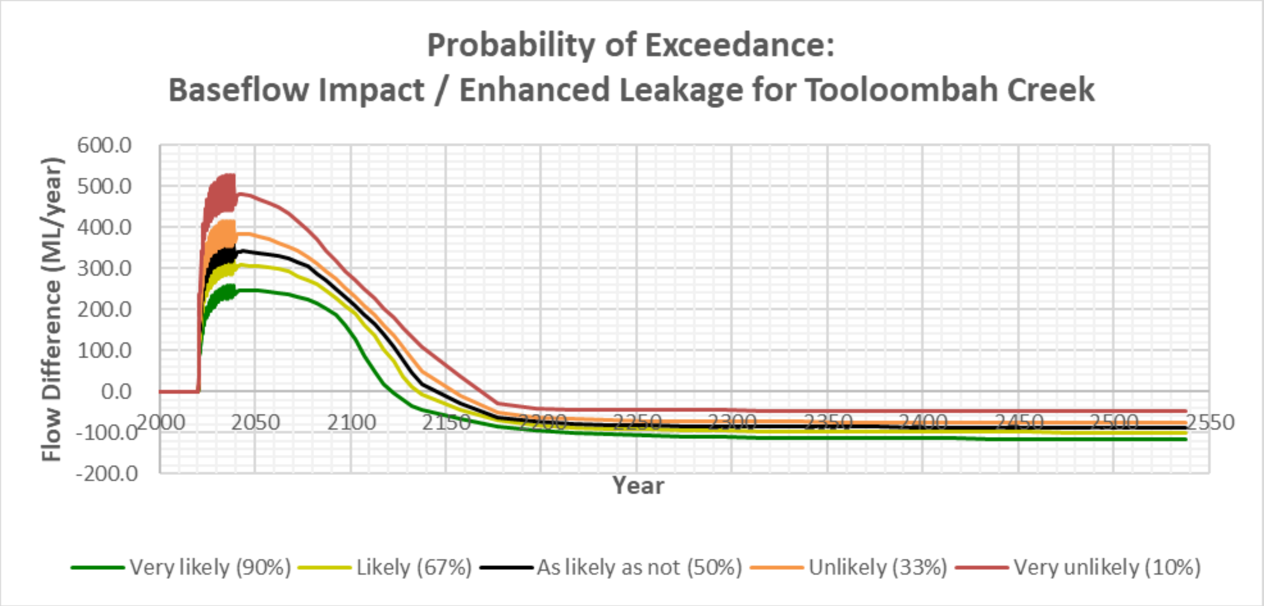


Figure 2: Time-series baseflow impact / enhanced leakage for Tooloombah Creek.

Time series flows: baseflow impact / enhanced leakage for Styx River

Figure 2 shows baseflow impact / enhanced leakage over time from Styx River at 10%, 33%, 50%, 67% and 90% probabilities of exceedance.

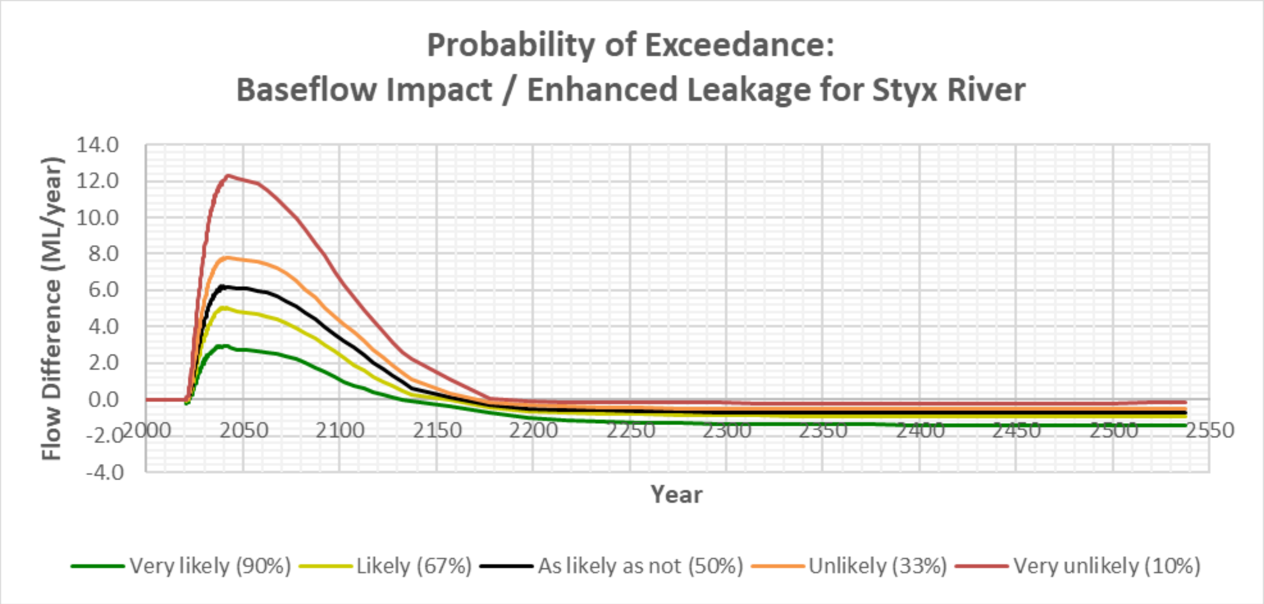


Figure 3: Time-series baseflow impact / enhanced leakage for Styx River.

Time series flows: baseflow impact / enhanced leakage for Deep Creek

Figure 2 shows baseflow impact / enhanced leakage over time for Deep Creek at 10%, 33%, 50%, 67% and 90% probabilities of exceedance.

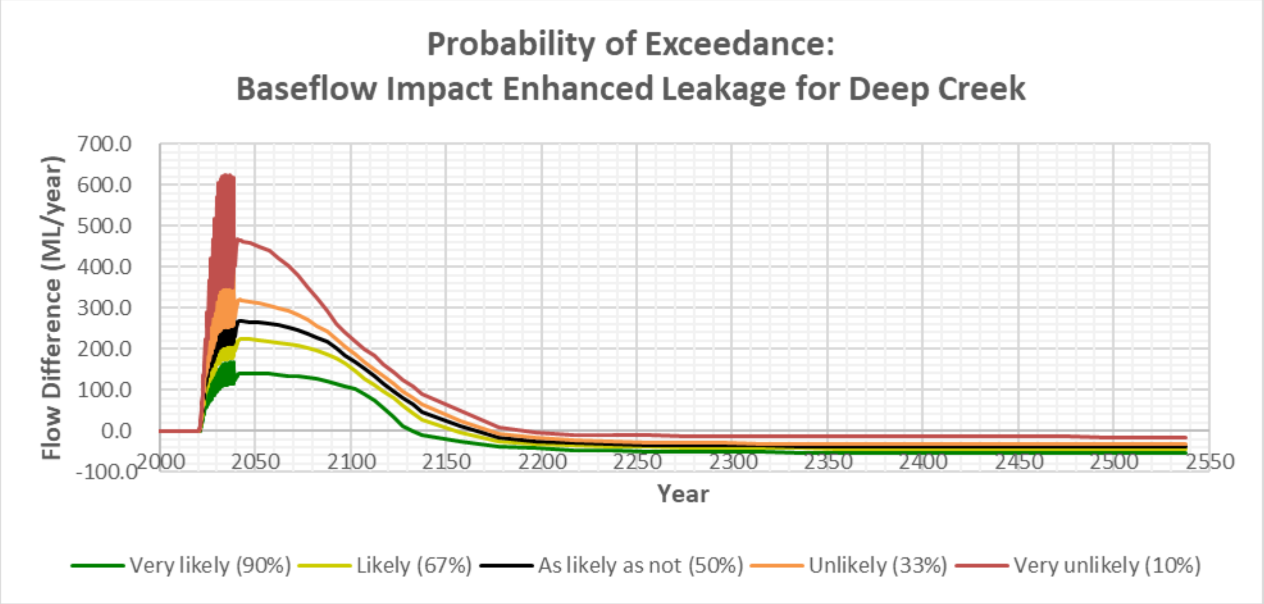


Figure 4: Time-series baseflow impact / enhanced leakage for Deep Creek.

Time series flows: baseflow impact / enhanced leakage for Mamelon Creek

Figure 2 shows baseflow impact / enhanced leakage over time for Mamelon Creek at 10%, 33%, 50%, 67% and 90% probabilities of exceedance.

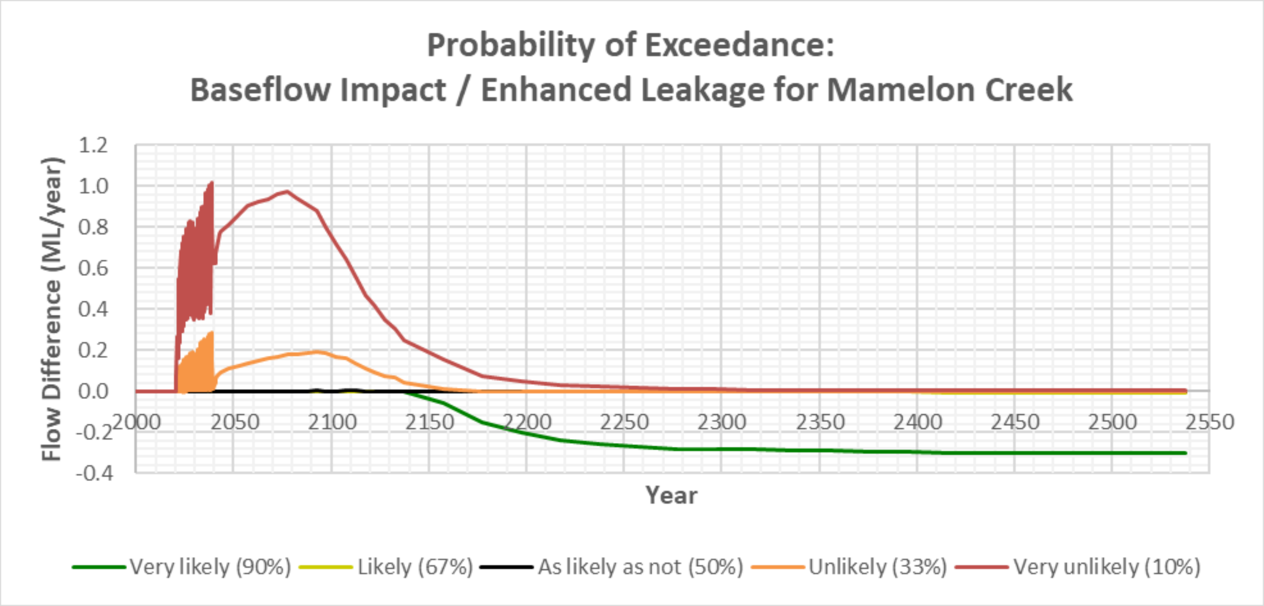


Figure 5: Time-series baseflow impact / enhanced leakage for Mamelon Creek.

Spatial drawdown: probability of exceedance

Spatial drawdown statistics, computed from cell by cell model results, are contoured on a “probability of exceedance” basis in Figure 6 through Figure 11, for layers 2, 3, 5, 8, 11 and 12. The value of each contour represents the probability of drawdown exceeding 2m inside the area of the contour at any time during mine operation or post-closure. Contour lines are presented at 10%, 33%, 50%, 67% and 90% probabilities.

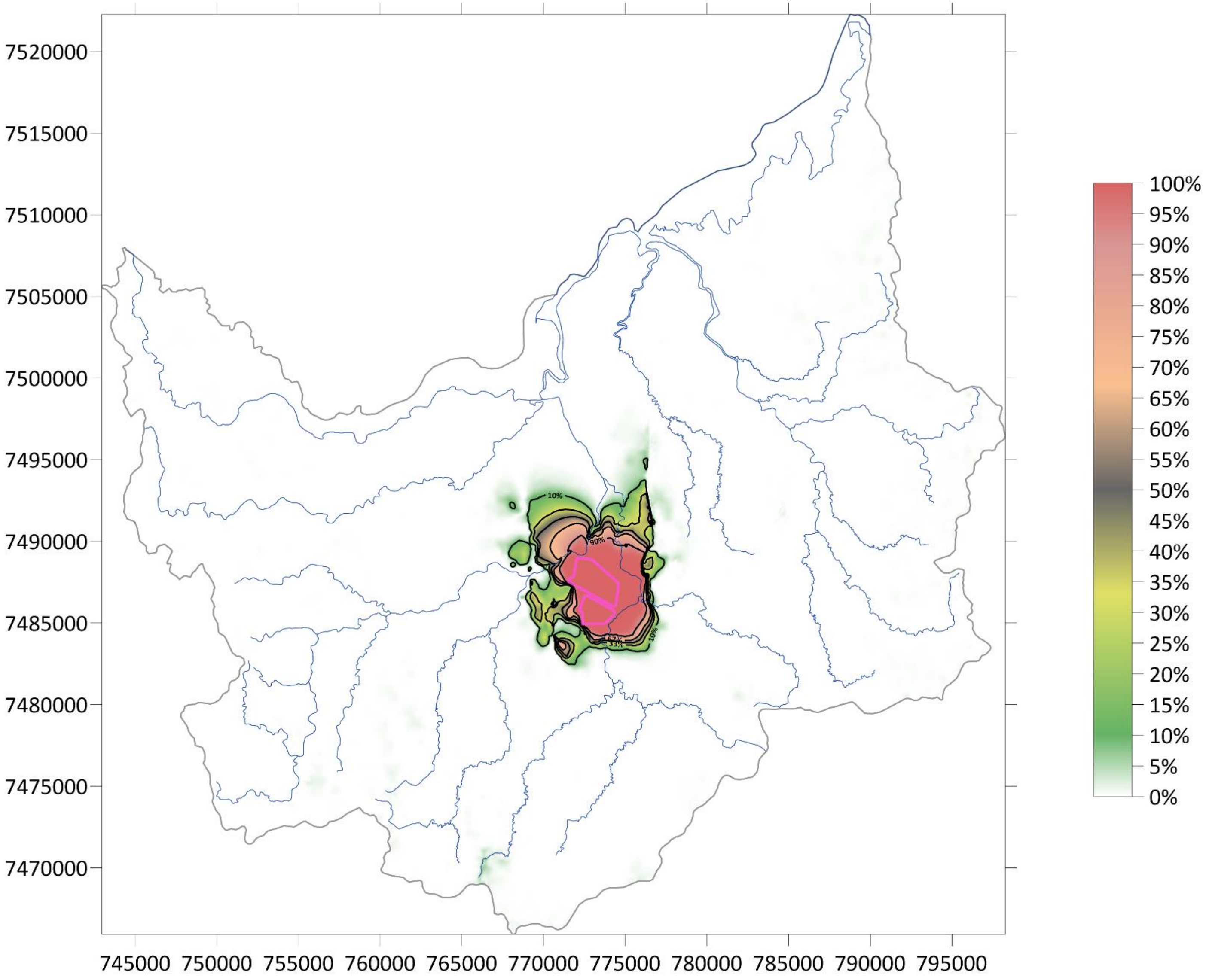


*Figure 6: Probability of exceedance of 2m drawdown in **layer 2**.*

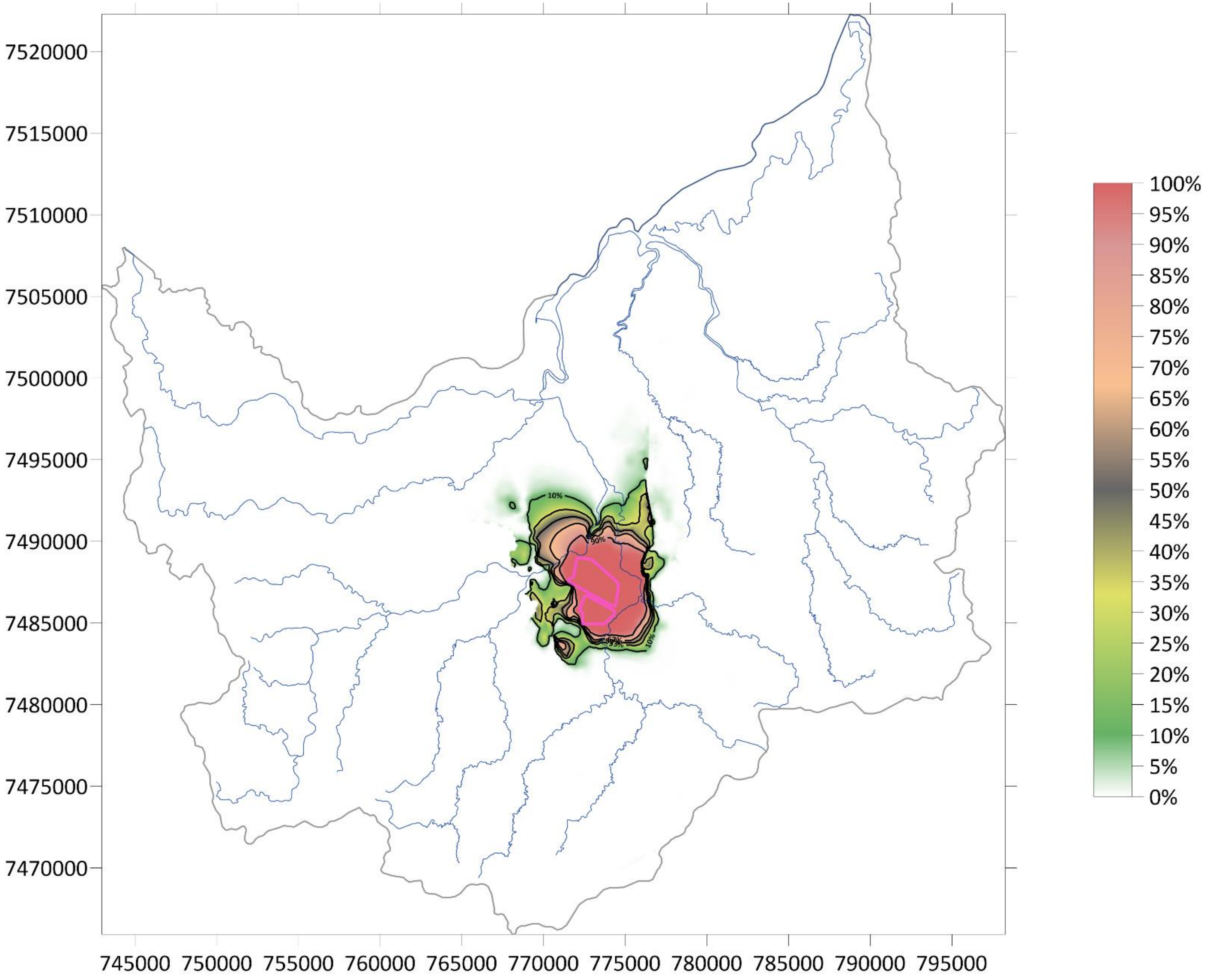


Figure 7: Probability of exceedance of 2m drawdown in ***layer 3****.*

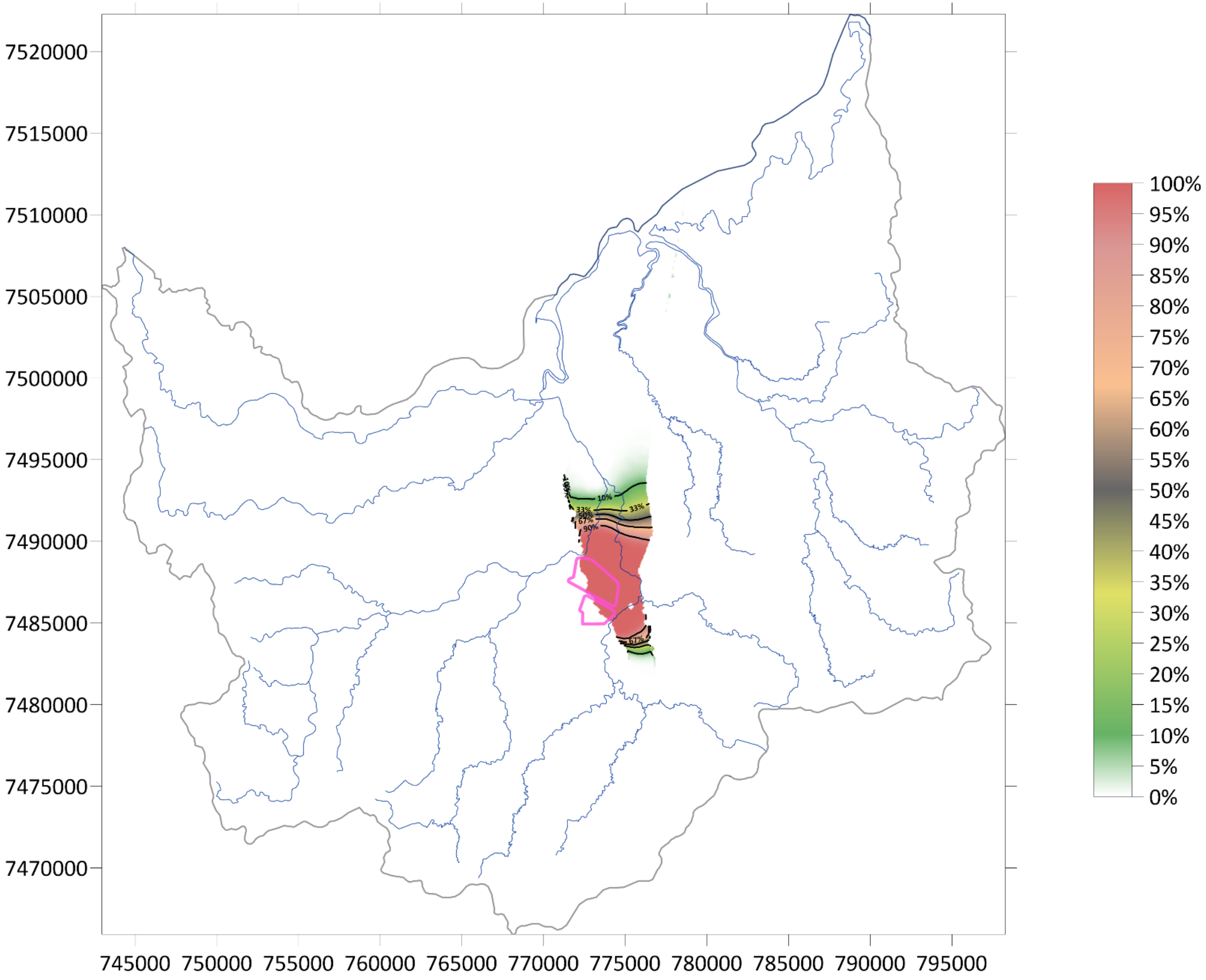


Figure 8: Probability of exceedance of 2m drawdown in ***layer 5****.*

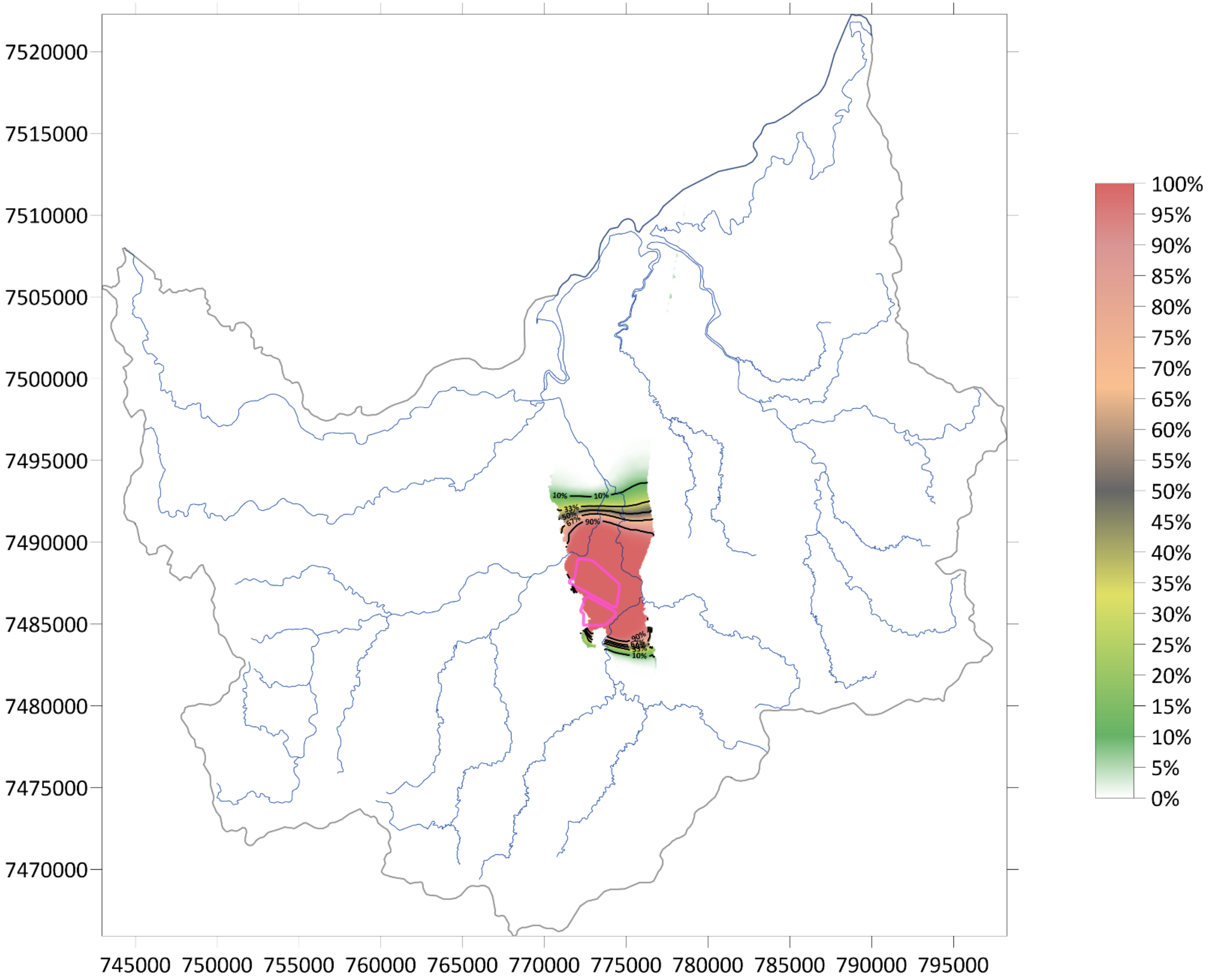


*Figure 9: Probability of exceedance of 2m drawdown in **layer 8**.*

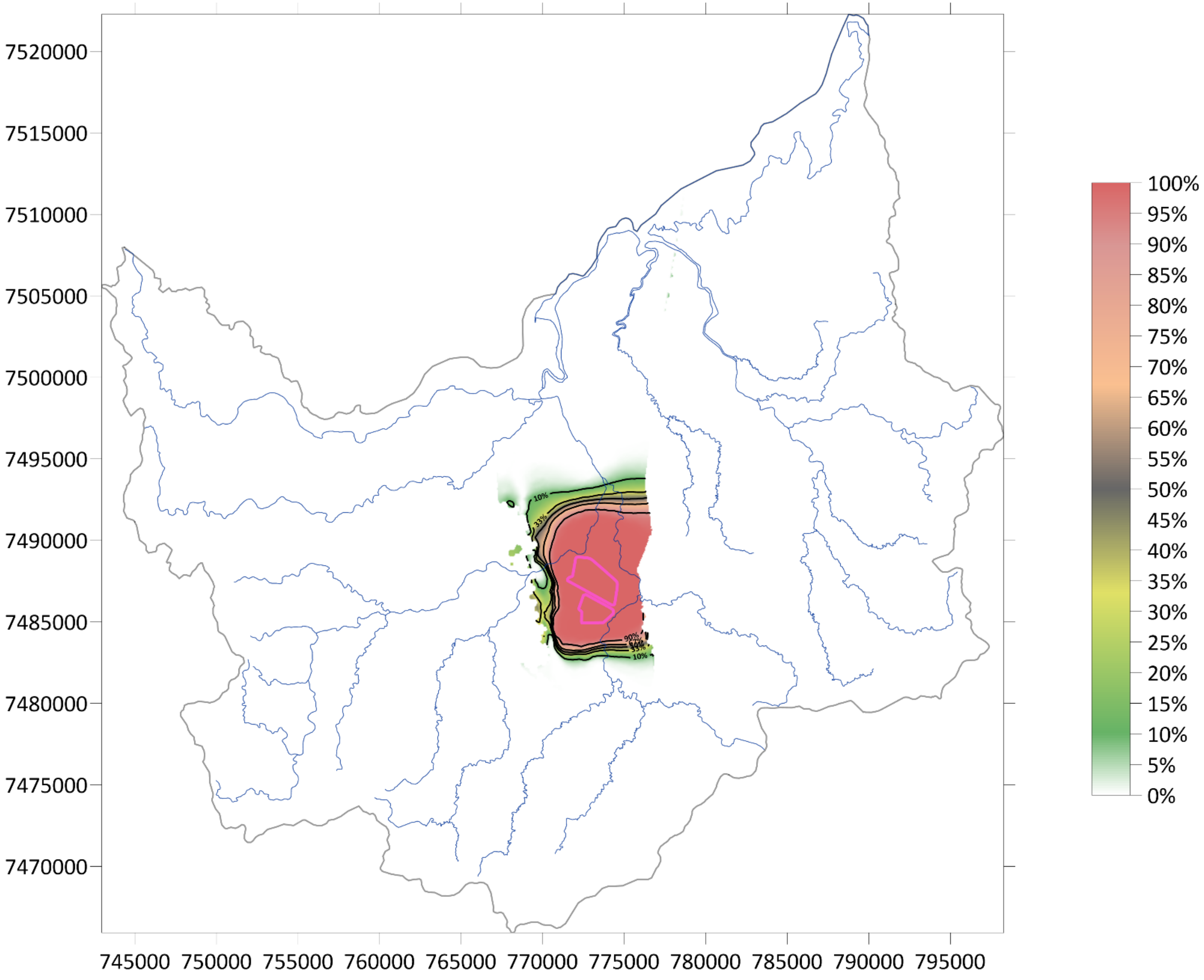


*Figure 10: Probability of exceedance of 2m drawdown in **layer 11**.*

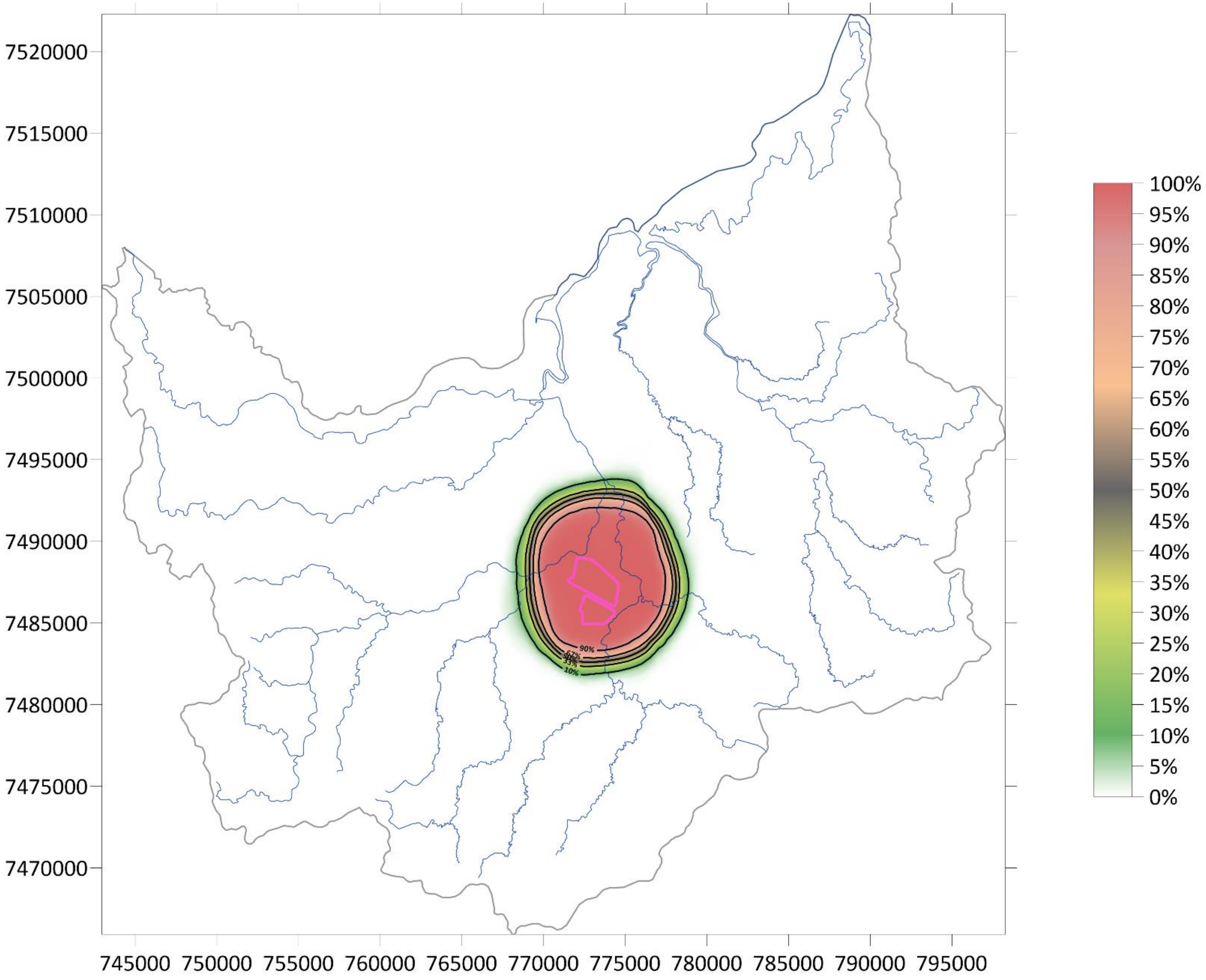


*Figure 11: Probability of exceedance of 2m drawdown in **layer 12**.*

Spatial drawdown: maximum drawdown at percentiles

Figure 12 through Figure 29 show contours of maximum drawdown (over all simulation time) at 10th, 50th and 90th percentiles for layers 2, 3, 5, 8, 11 and 12. Each figure presents a dotted grey line showing the 1m drawdown contour, a solid red line showing the 2m drawdown contour, and subsequent grey lines showing 10m, 20m, and further contours at 10m intervals.

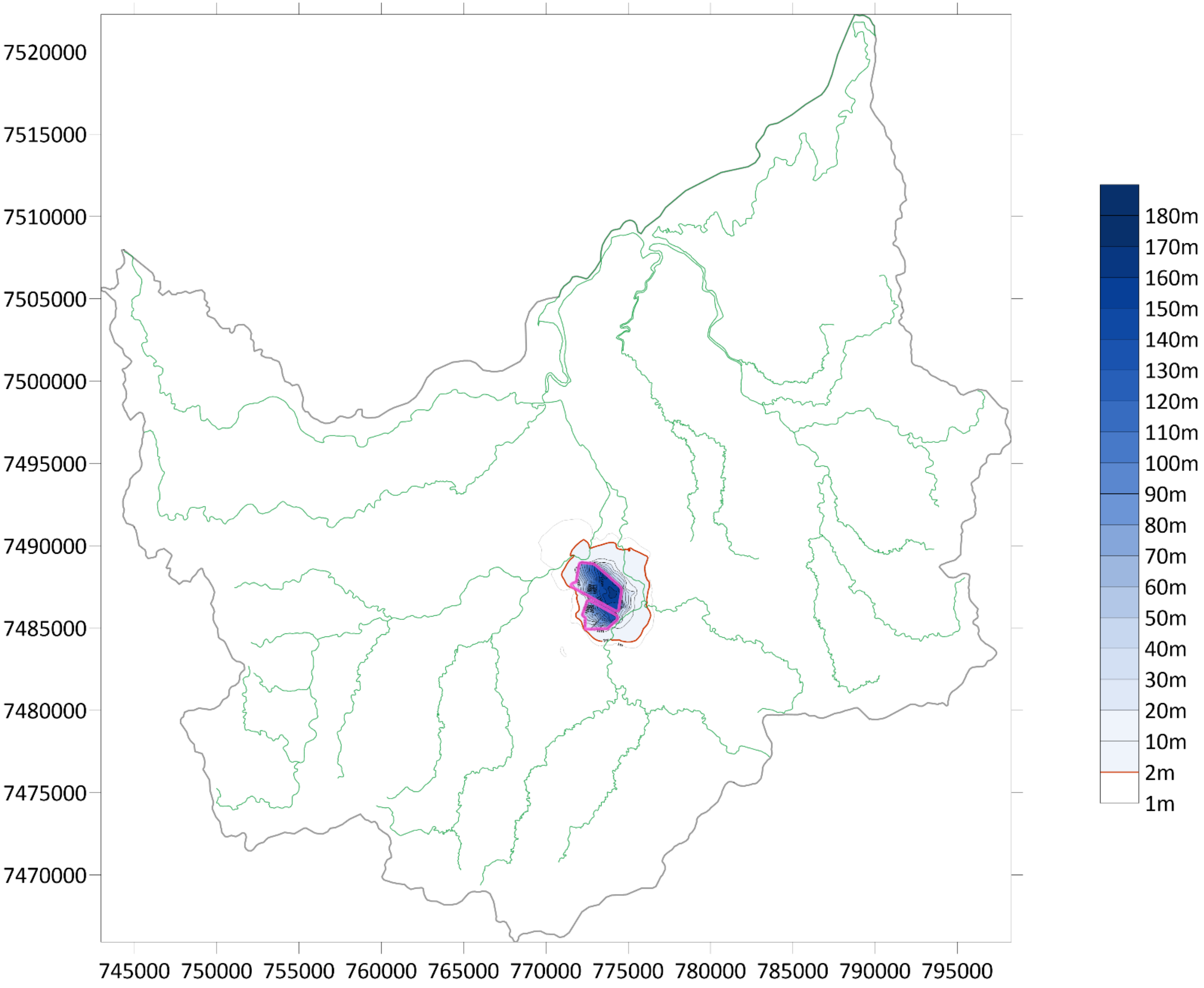


*Figure 12: **10th percentile** maximum drawdown (over all time) in **layer 2**.*

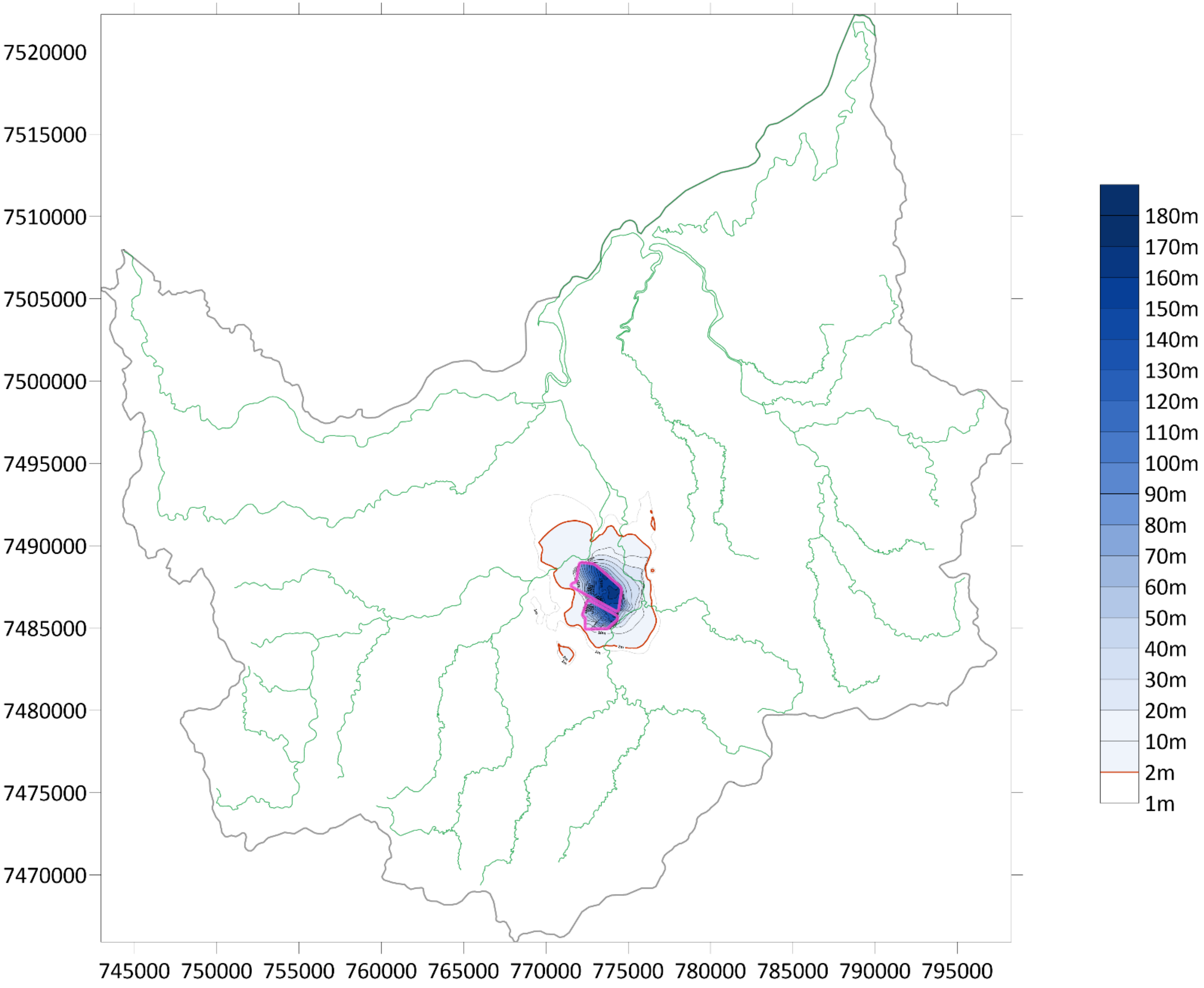


*Figure 13: **50th percentile** maximum drawdown (over all time) in **layer 2**.*

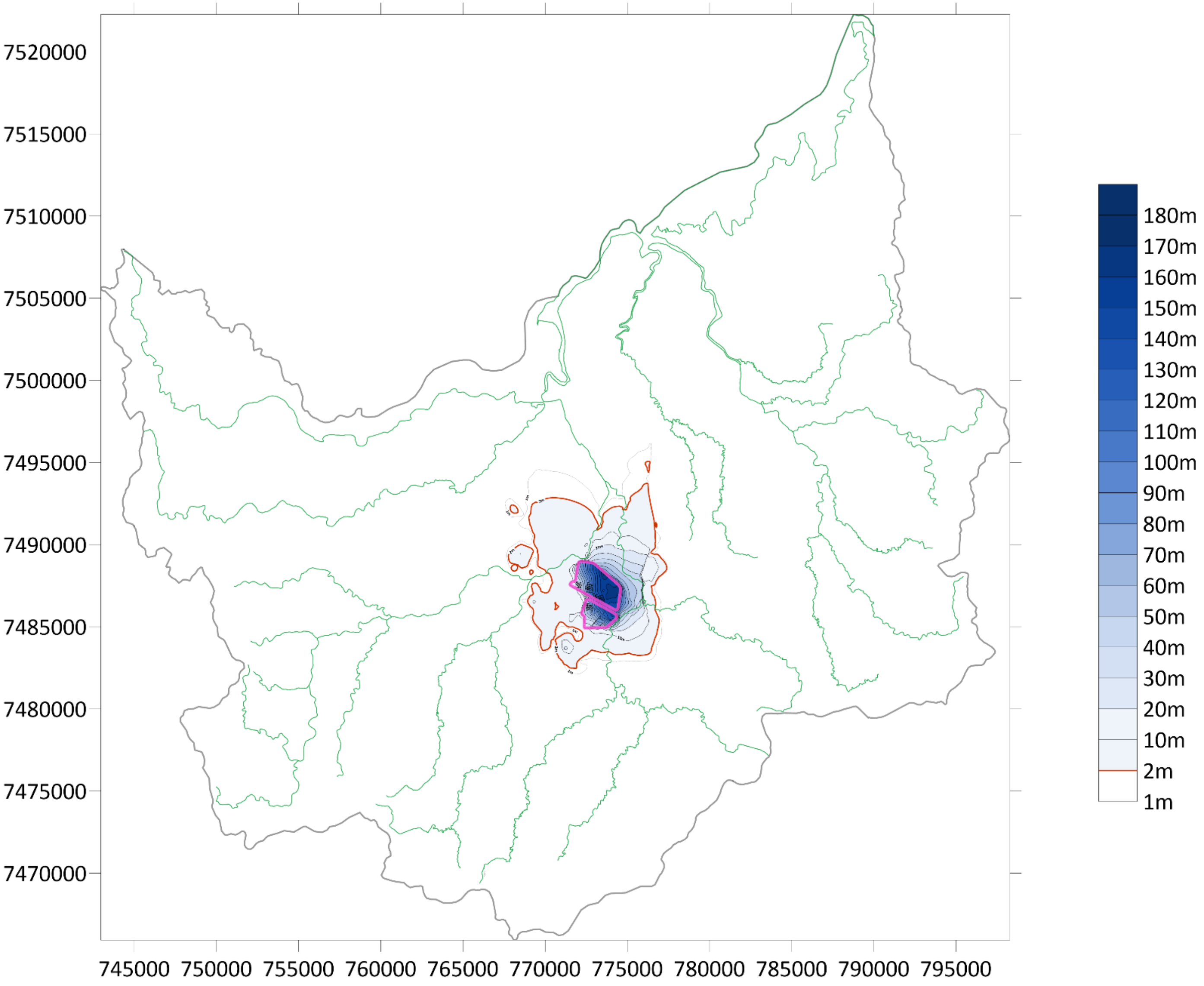


*Figure 14: **90th percentile** maximum drawdown (over all time) in **layer 2**.*

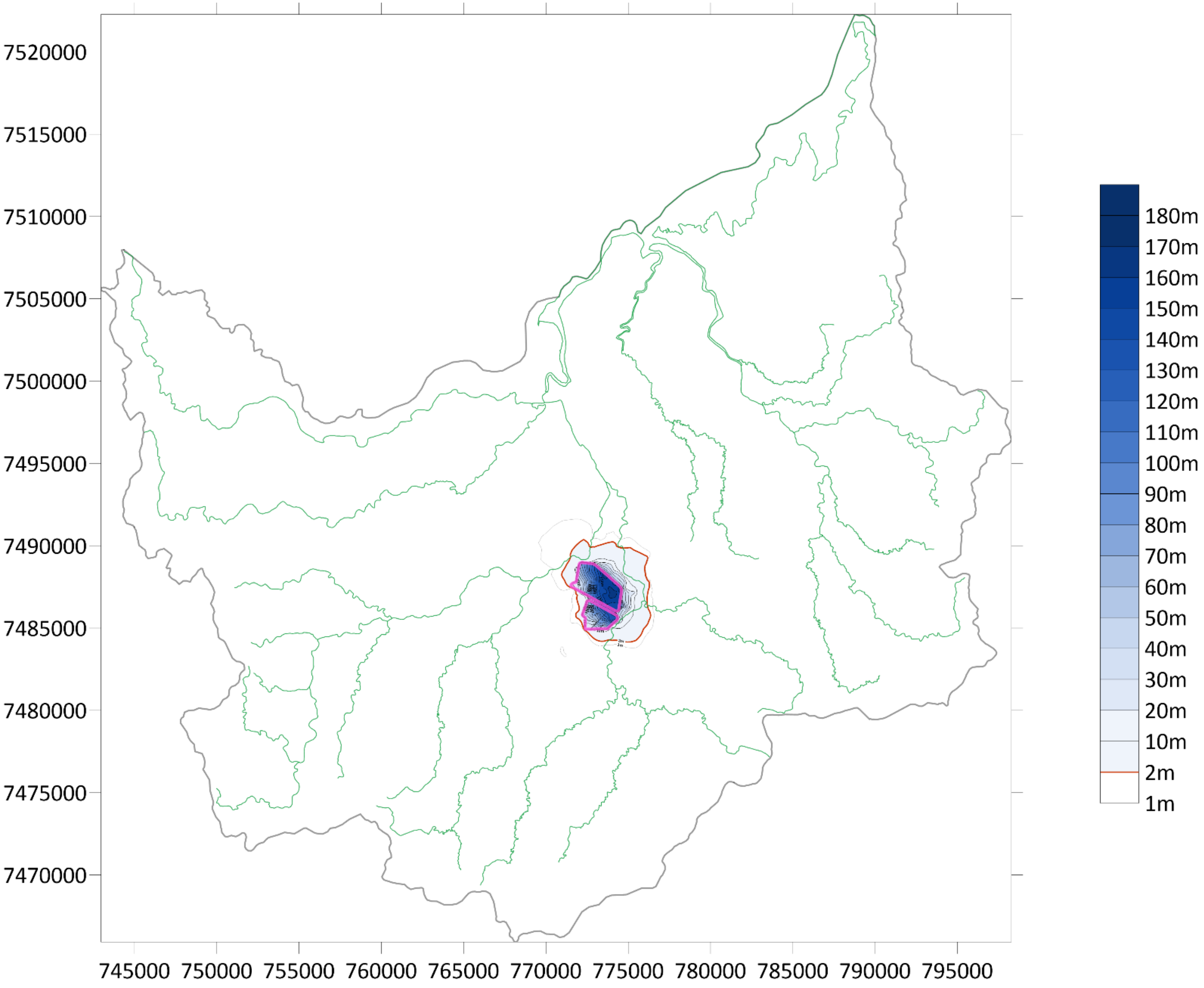


*Figure 15: **10th percentile** maximum drawdown (over all time) in **layer 3**.*

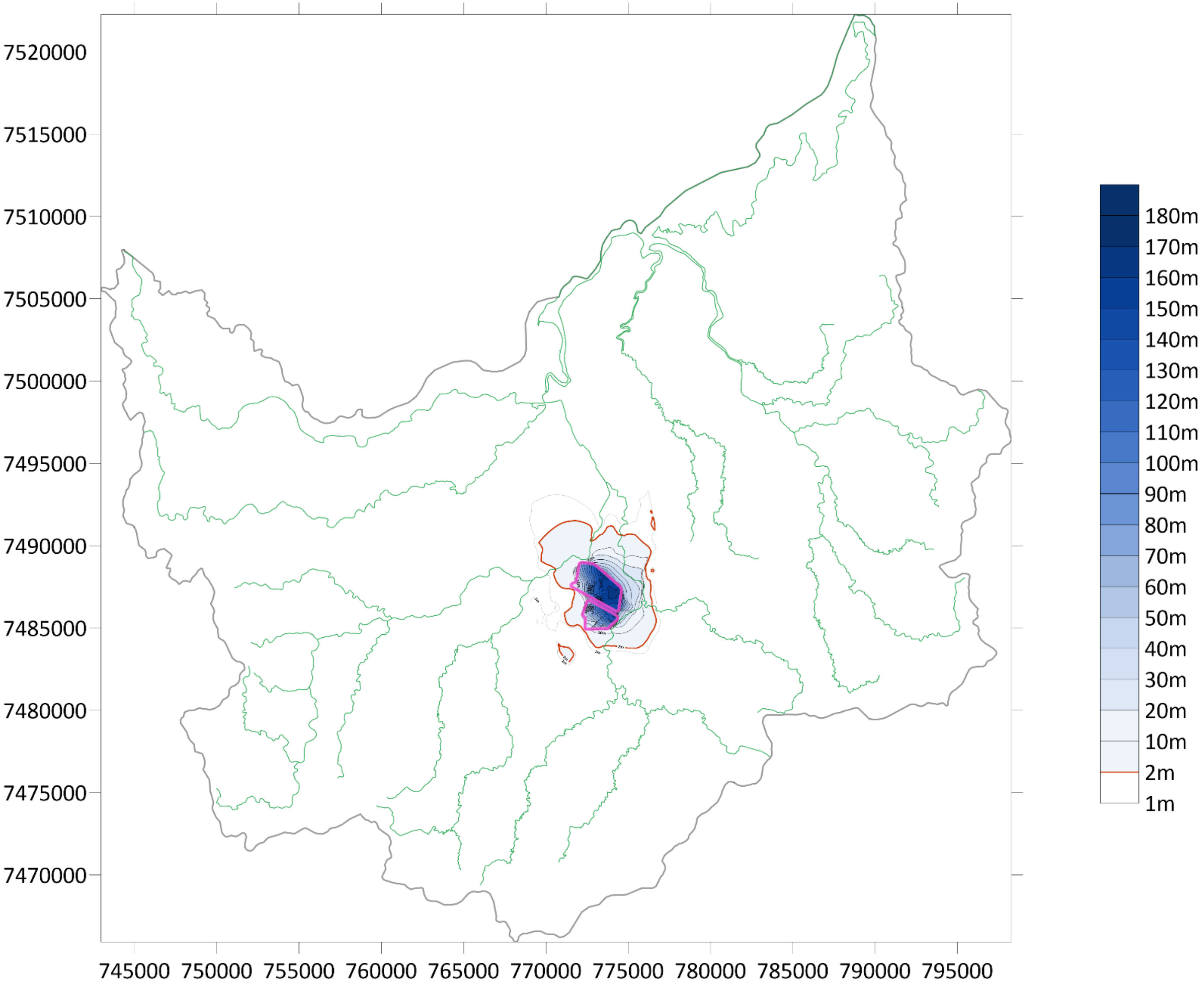


*Figure 16: **50th percentile** maximum drawdown (over all time) in **layer 3**.*

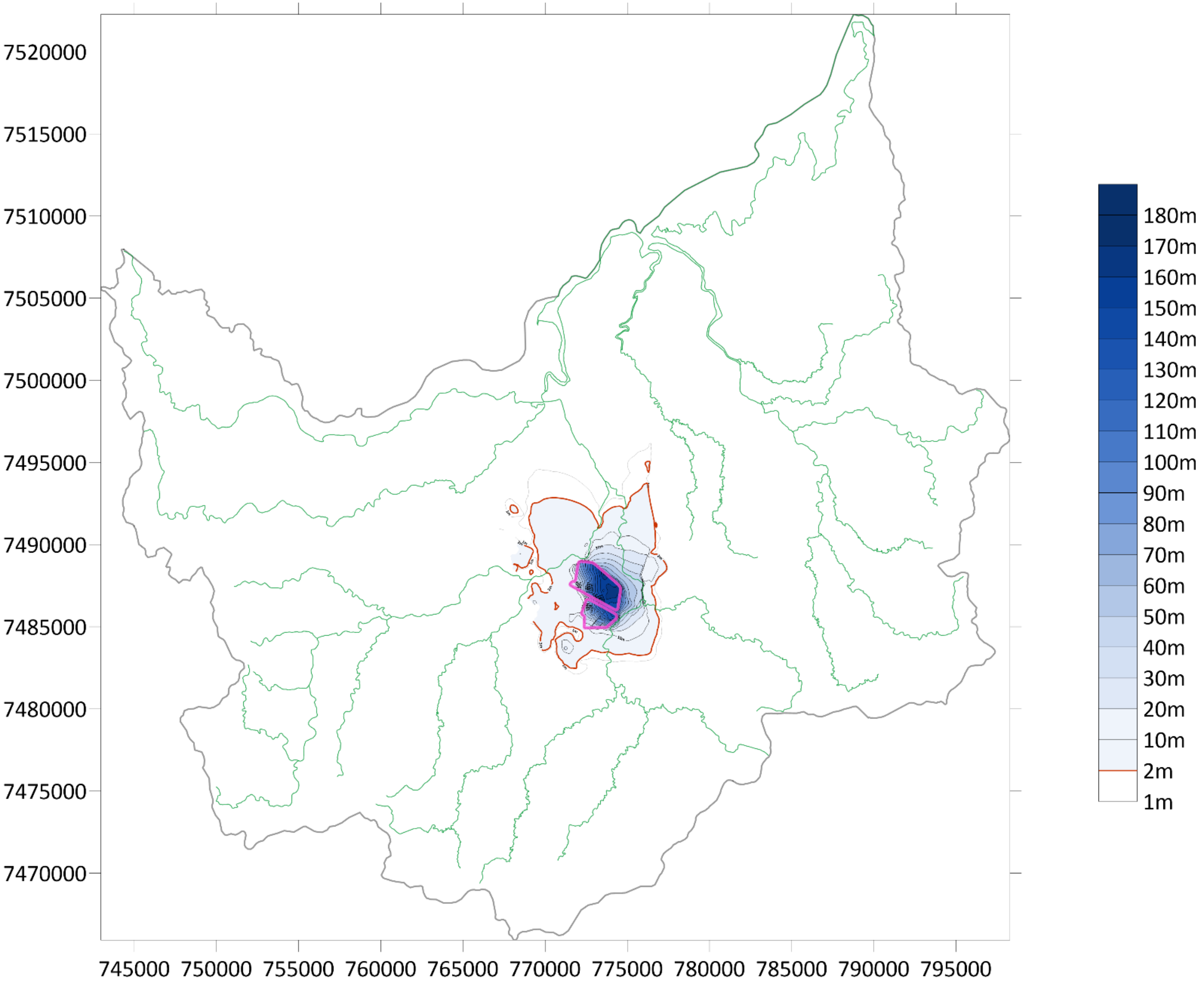


*Figure 17: **90th percentile** maximum drawdown (over all time) in **layer 3**.*

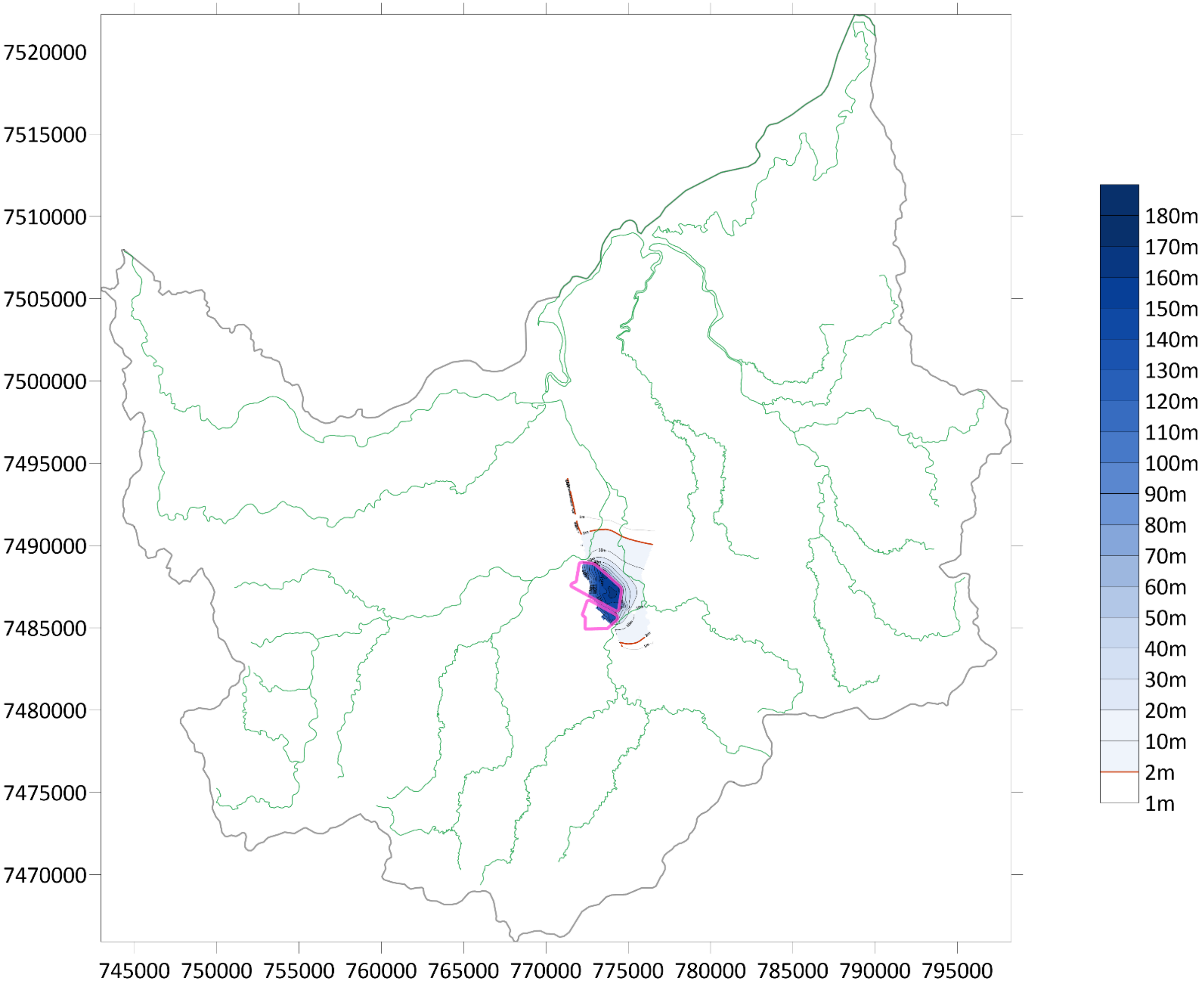


*Figure 18: **10th percentile** maximum drawdown (over all time) in **layer 5**.*

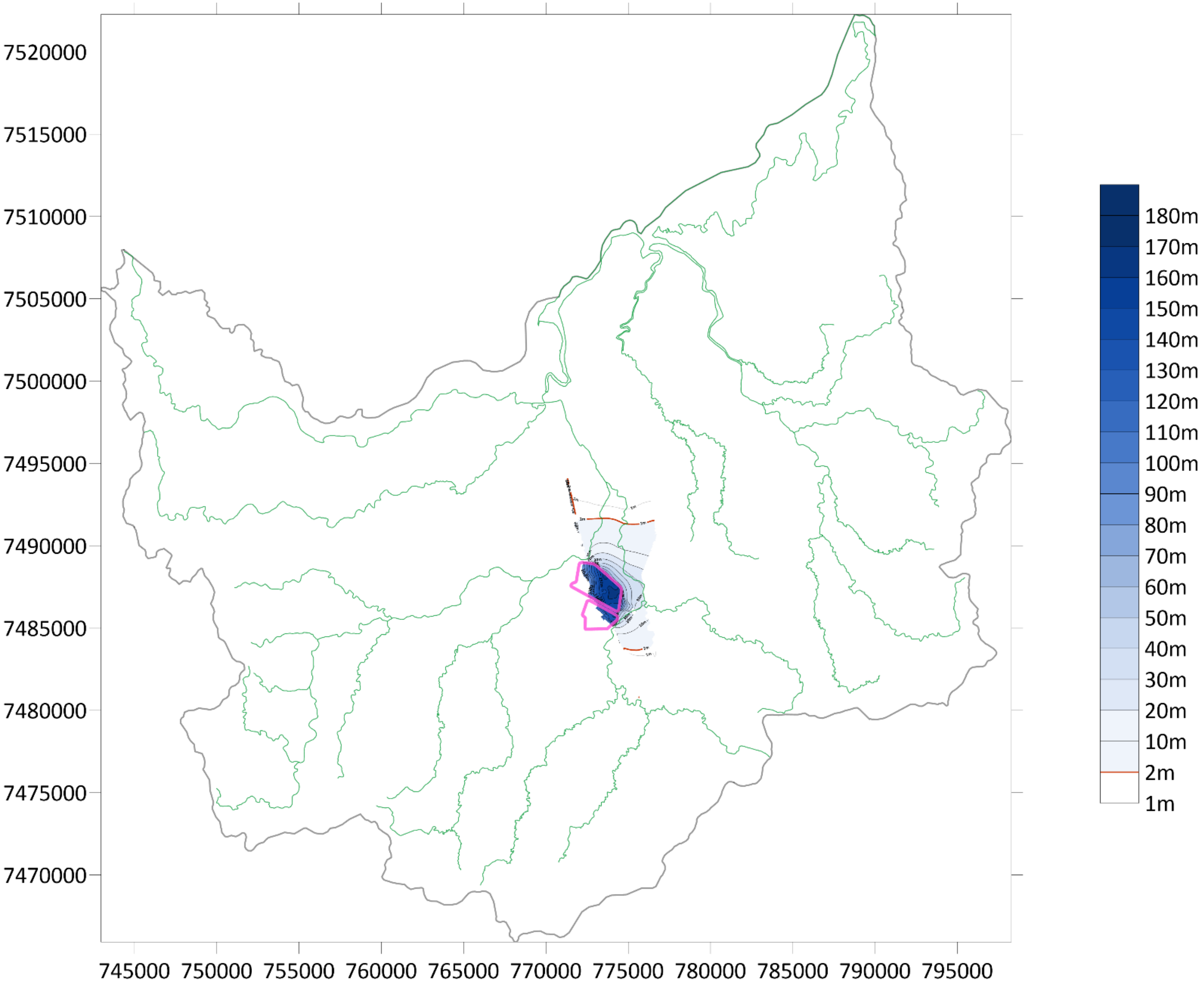


*Figure 19: **50th percentile** maximum drawdown (over all time) in **layer 5**.*

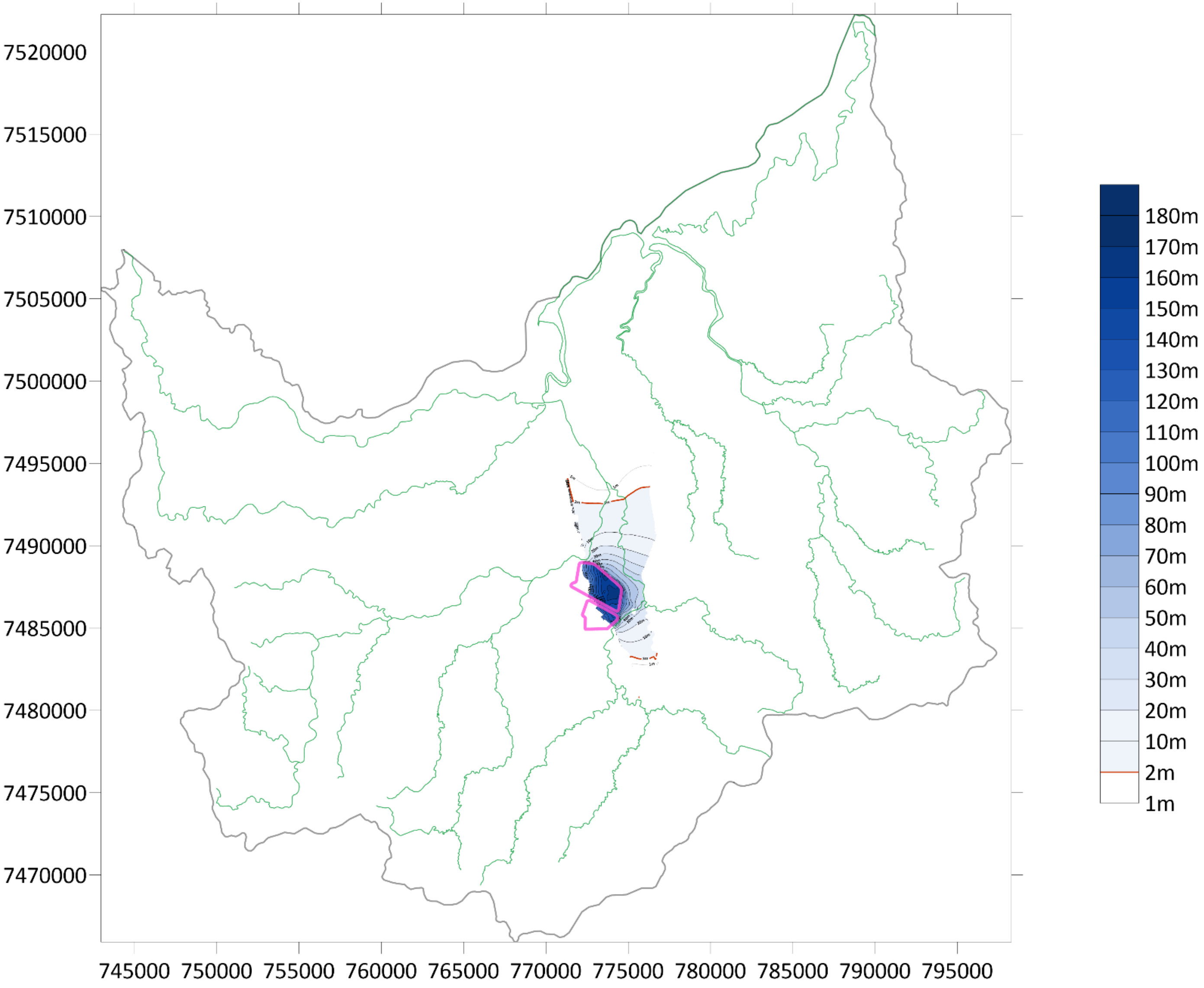


*Figure 20: **90th percentile** maximum drawdown (over all time) in **layer 5**.*

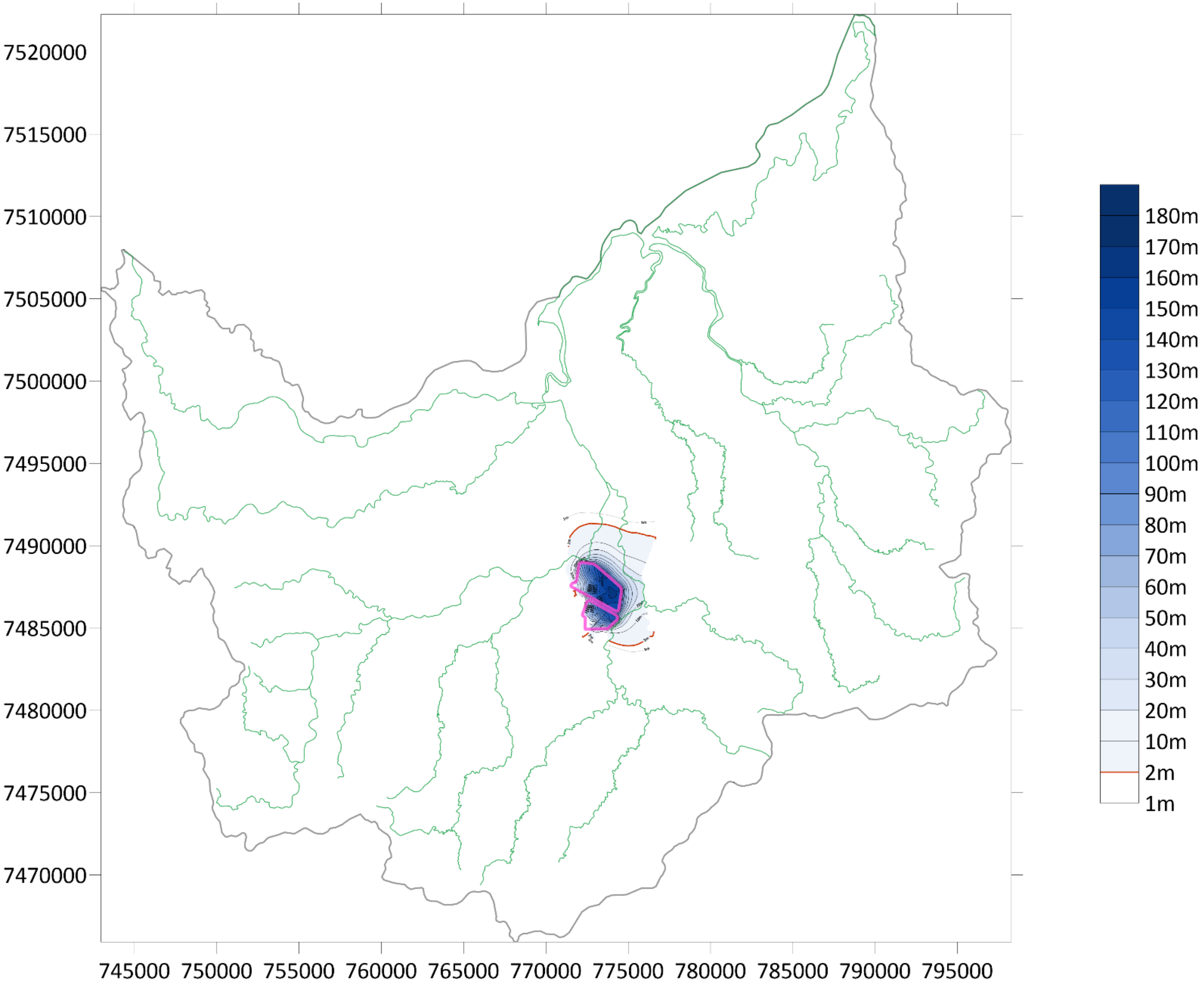


*Figure 21: **10th percentile** maximum drawdown (over all time) in **layer 8**.*

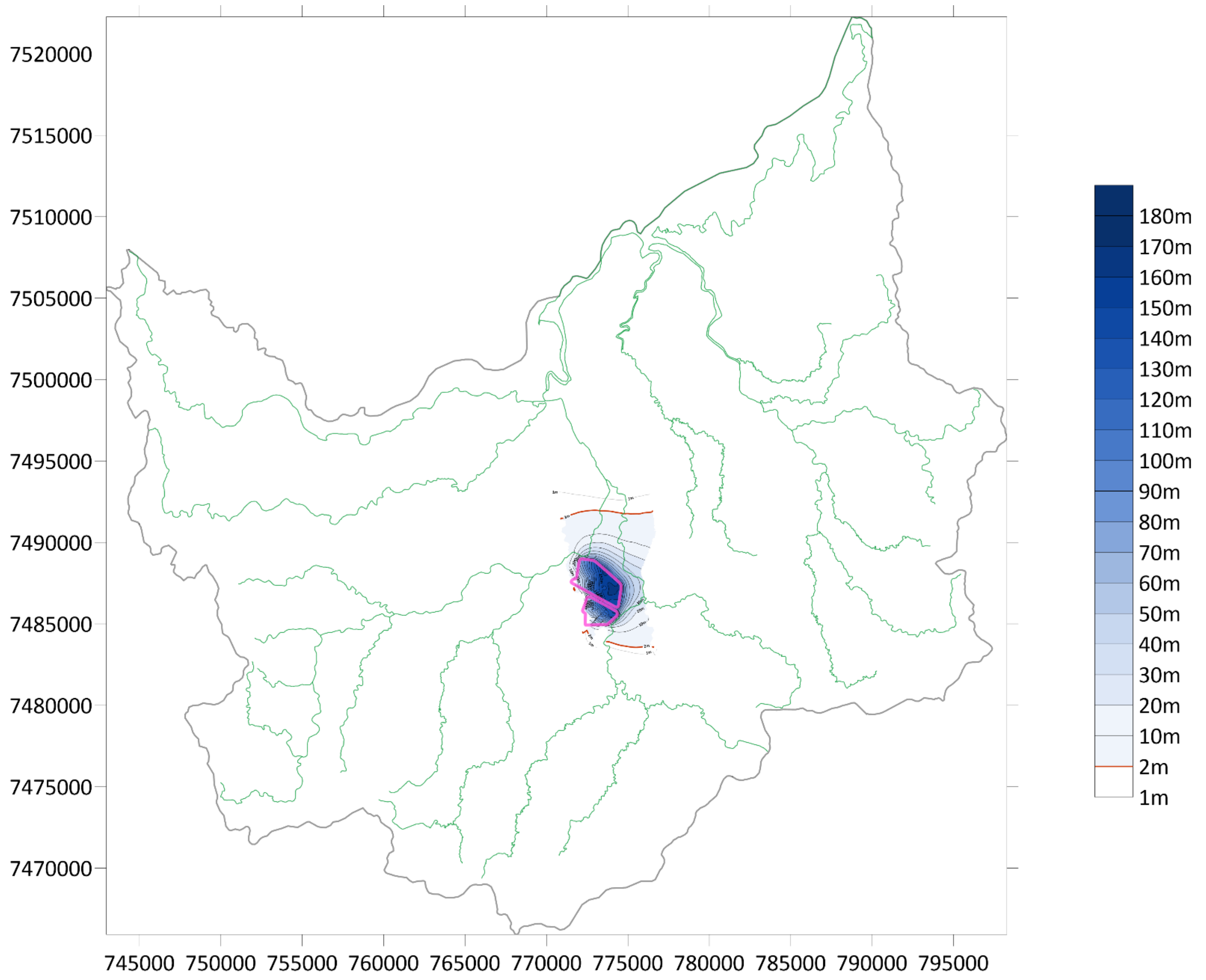


*Figure 22: **50th percentile** maximum drawdown (over all time) in **layer 8**.*

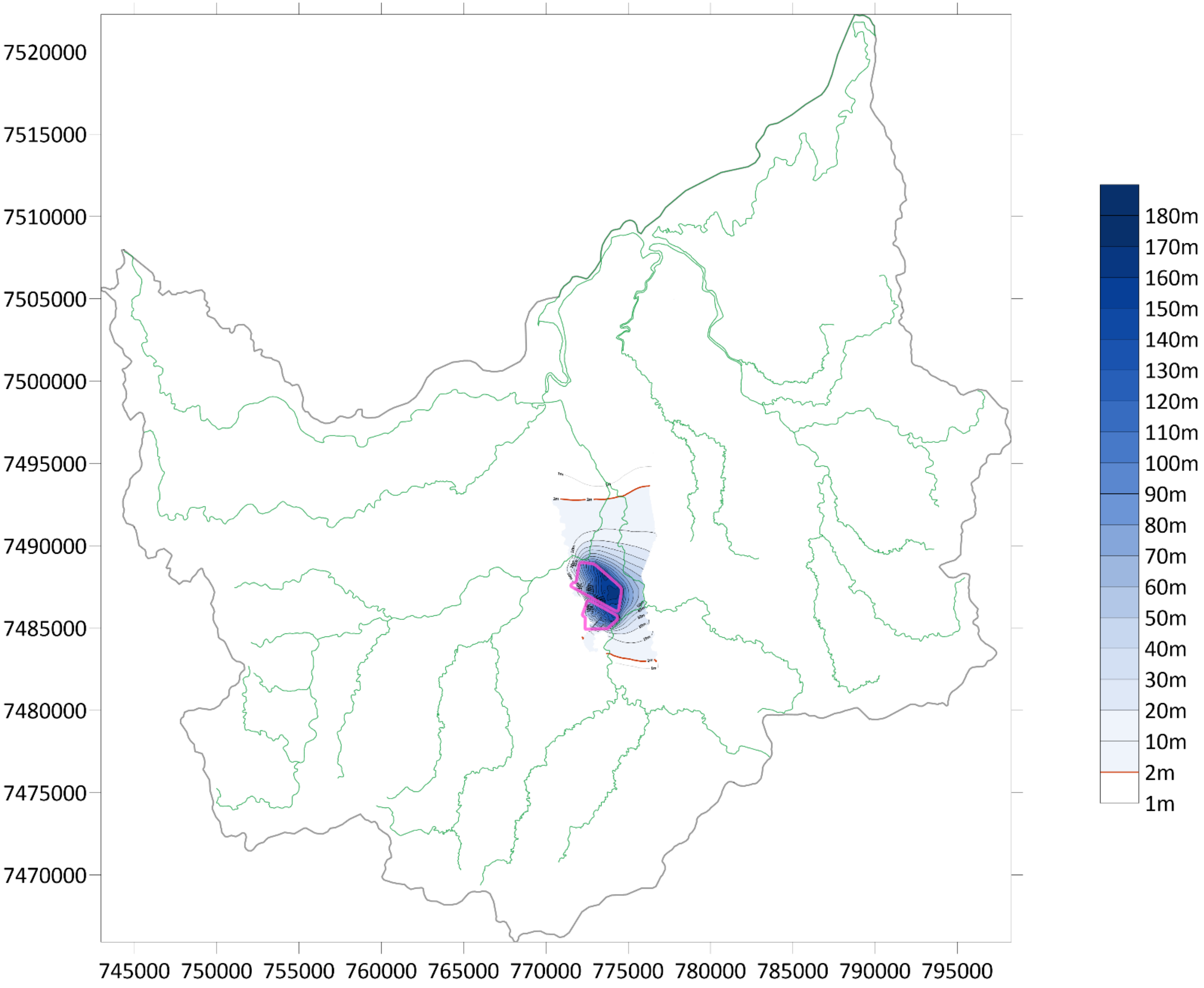


*Figure 23: **90th percentile** maximum drawdown (over all time) in **layer 8**.*

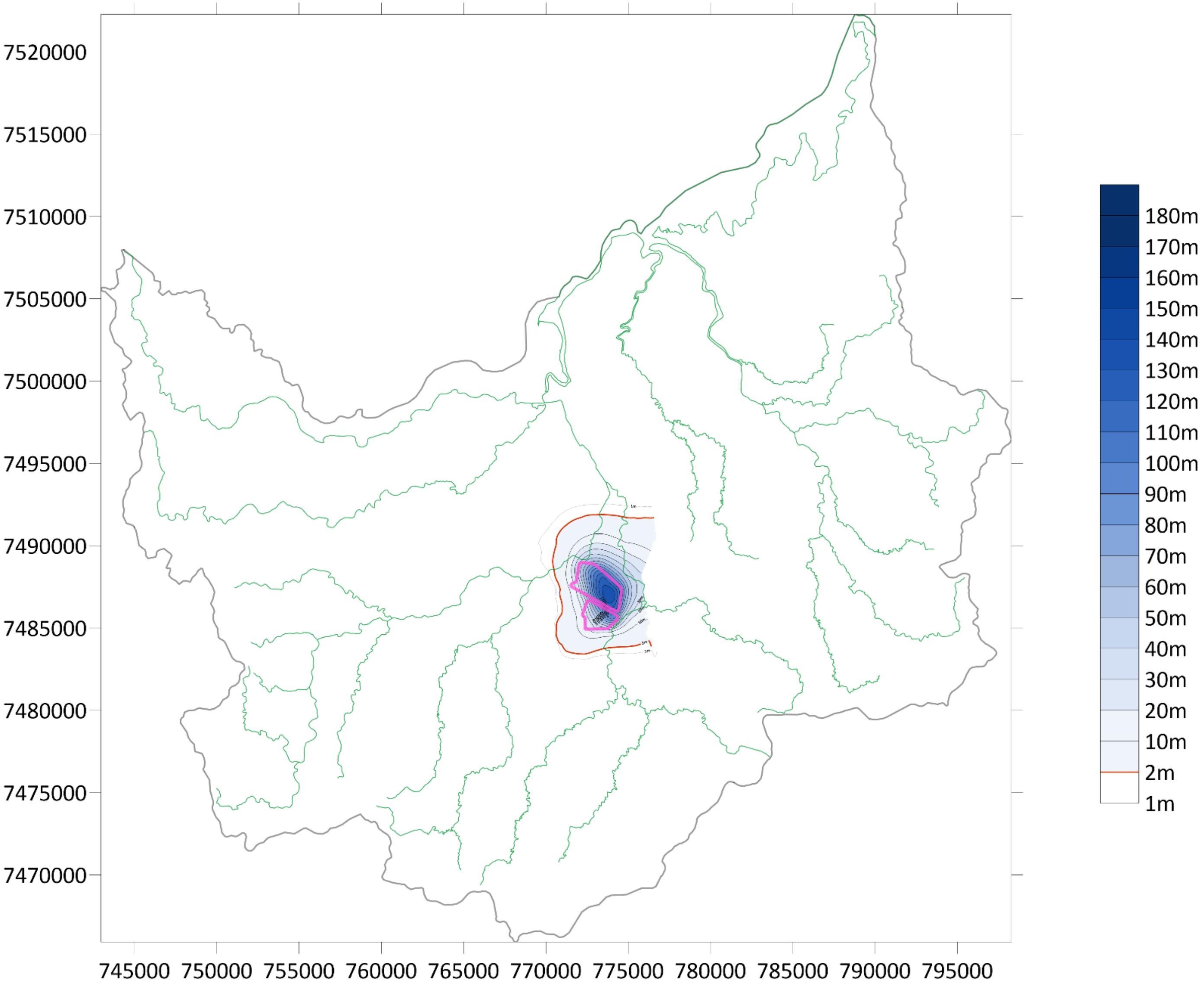


*Figure 24: **10th percentile** maximum drawdown (over all time) in **layer 11**.*

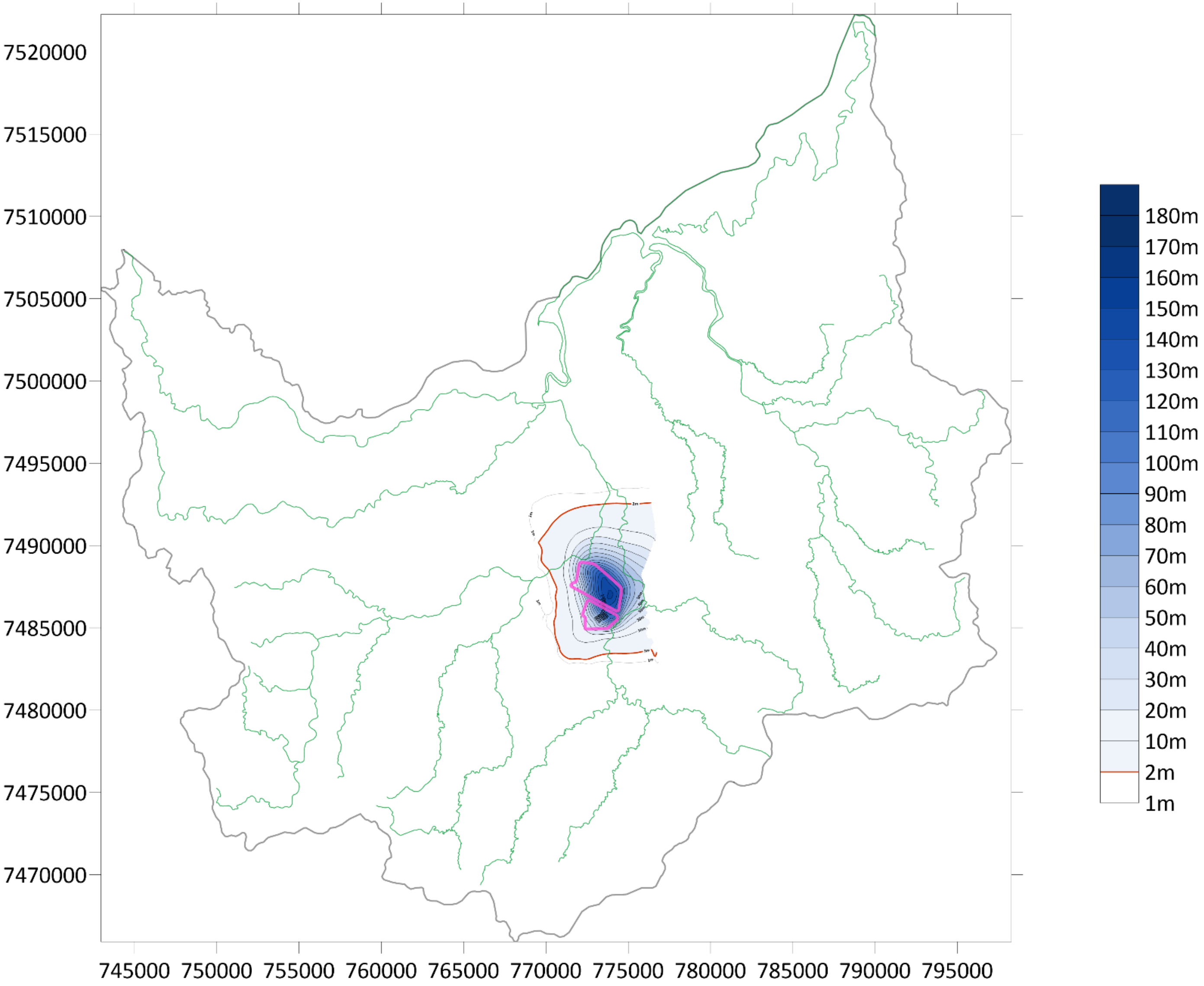


*Figure 25: **50th percentile** maximum drawdown (over all time) in **layer 11**.*

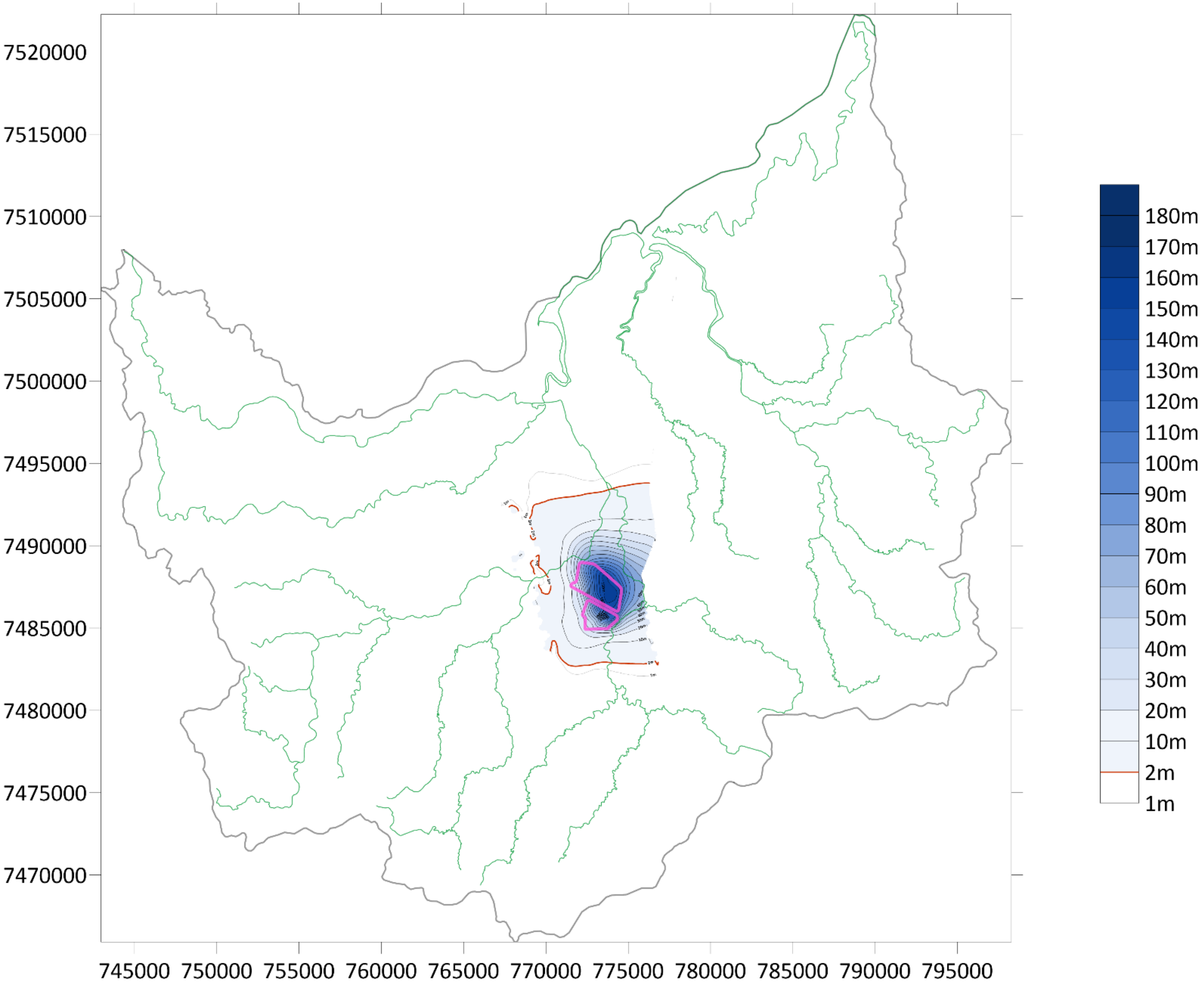


*Figure 26: **90th percentile** maximum drawdown (over all time) in **layer 11**.*

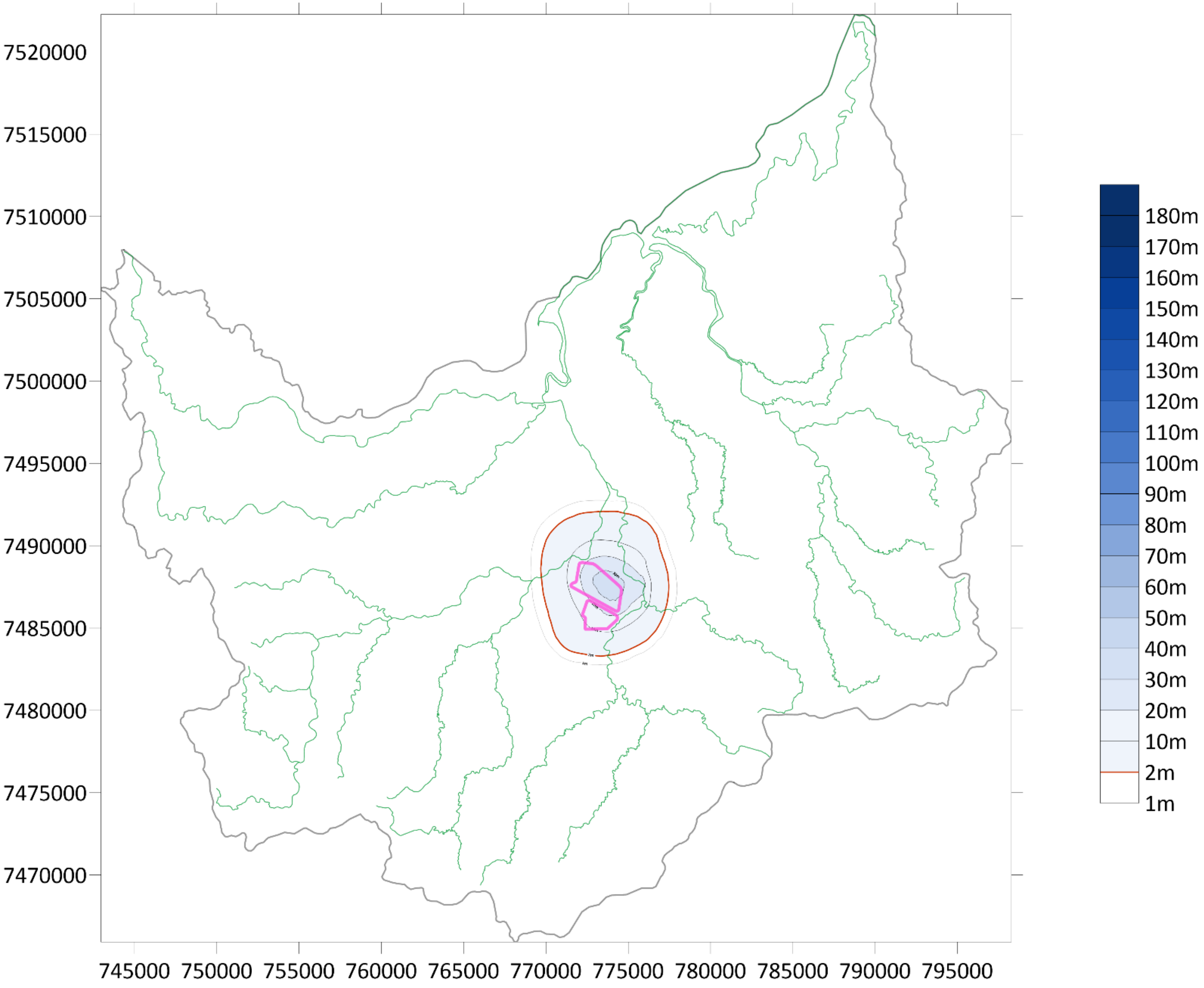


*Figure 27: **10th percentile** maximum drawdown (over all time) in **layer 12**.*

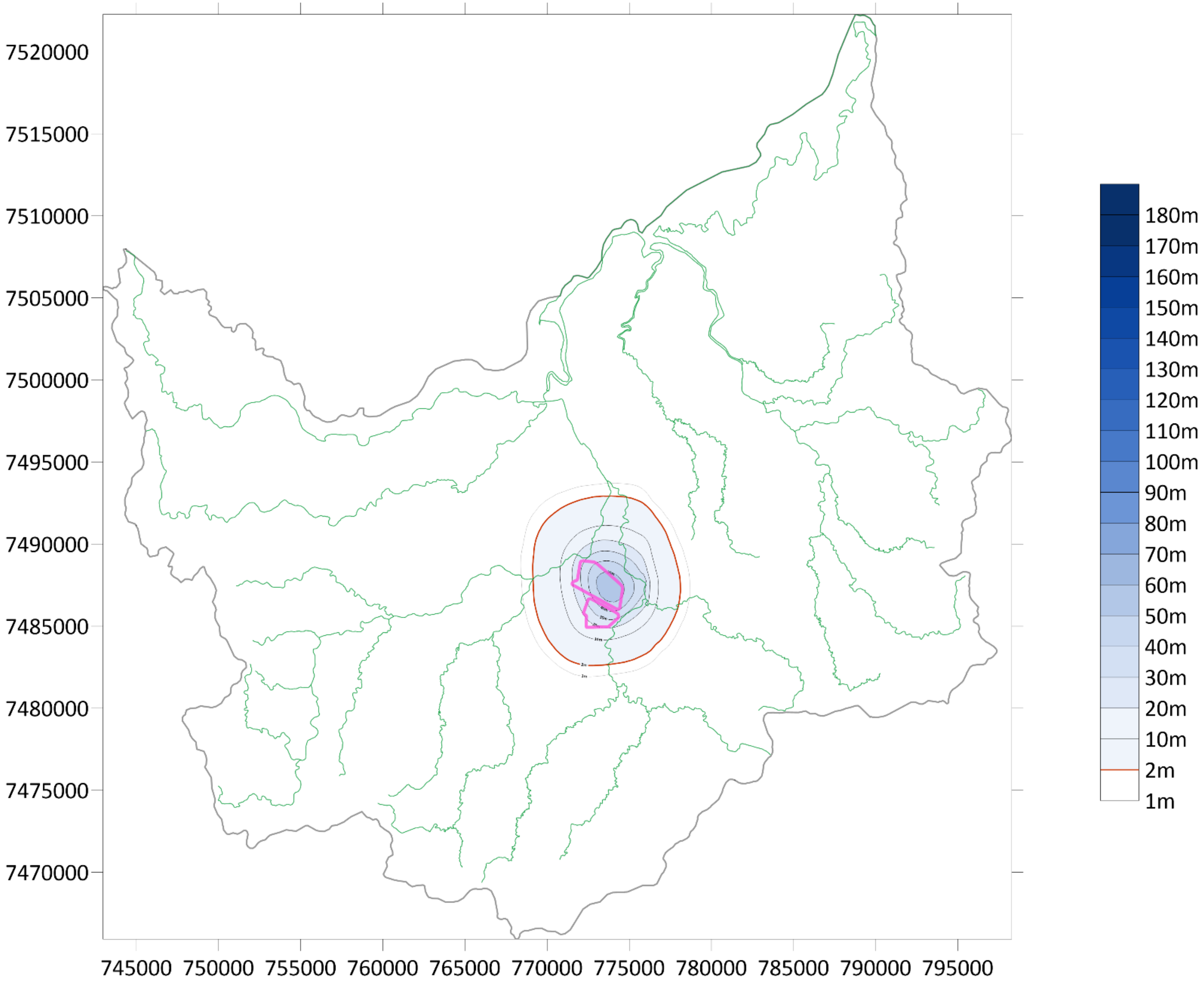


*Figure 28: **50th percentile** maximum drawdown (over all time) in **layer 12**.*

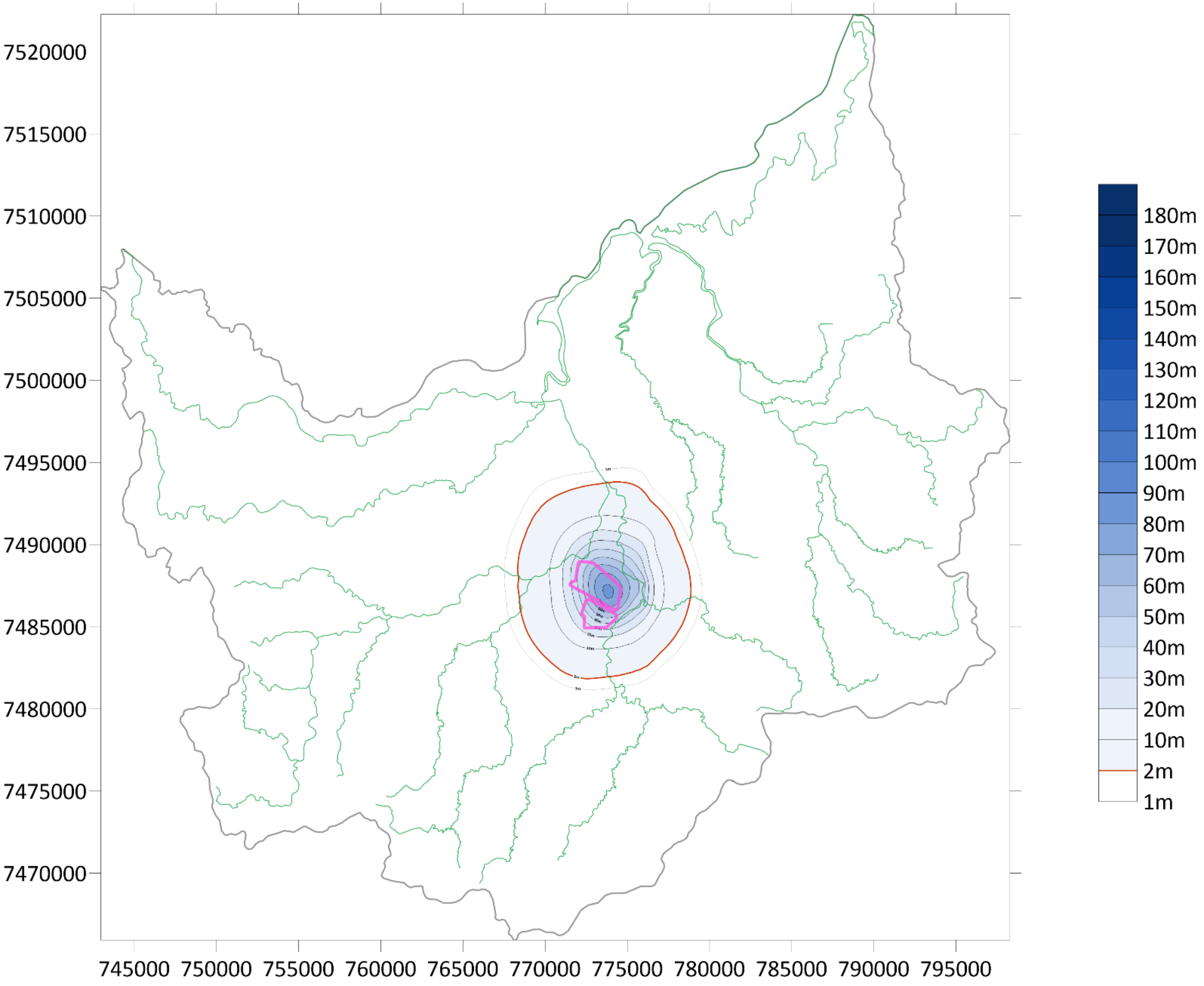


*Figure 29: **90th percentile** maximum drawdown (over all time) in **layer 12**.*

Convergence

When conducting stochastic modelling, it is important to ensure that enough realisations are evaluated such that the results reported are accurate – that is, that the stochastic process has *converged* to within an acceptable probabilistic margin of error.

To gain confidence that the reported results were sufficiently close to their correct values, 99.7% confidence intervals were computed for the 10%, 33%, 50%, 67% and 90% probabilities of exceedance of selected aggregate metrics.

Confidence interval bounds for the $(100 \times p)^{\text{th}}$ percentile may be approximated by the formula $p \pm \sqrt{p(1-p)c^2/n}$, where c is the desired confidence in standard deviations of the normal distribution – $c = 3$ for 99.7% confidence – and n is the number of runs (see e.g. *Mood et al., 1974* for derivations of confidence interval bounds). For example, it may be said with 99.7% confidence after 602 successful runs that the true 90th percentile value lies between the 86.3rd and 93.7th percentile estimates ($= 100 \times \left(0.9 \pm \sqrt{0.9 \times 0.1 \times 9/602}\right)$).

In this section, charts are presented illustrating the convergence of selected key metrics to illustrate the convergence of the random sampling process. Two types of chart are presented. The first shows the values of the 10th, 33rd, 50th, 67th and 90th percentiles as they evolve with the number of runs evaluated. The second shows the 10th, 50th and 90th percentile values surrounded by their computed 99.7% confidence intervals, also as they evolve with respect to the number of runs evaluated. Note that 33rd and 67th percentile confidence intervals have been omitted from these charts to ease readability; the intervals in these cases were similar or narrower in width than those of the 10th, 50th and 90th percentiles shown.

The colour coding of the convergence charts follows the same categorisation as in the other charts presented: "very likely (90%) - **green**, "likely (67%)" - **light yellow-green**, "about as likely as not (50%)" - **black**, "unlikely (33%)" - **orange**, and "very unlikely (10%)" - **red**. Solid lines in the convergence charts represent the actual sampled percentile values, and dashed lines represent the 99.7% confidence intervals of the percentile corresponding to their colour.

Peak mine inflow (combined)

Figure 30 and Figure 31 show the change in percentiles of peak total mine inflow with respect to the number of runs evaluated. The 99.7% confidence intervals indicate that the reported values are within 104.08 ML/year of the true values with high probability.

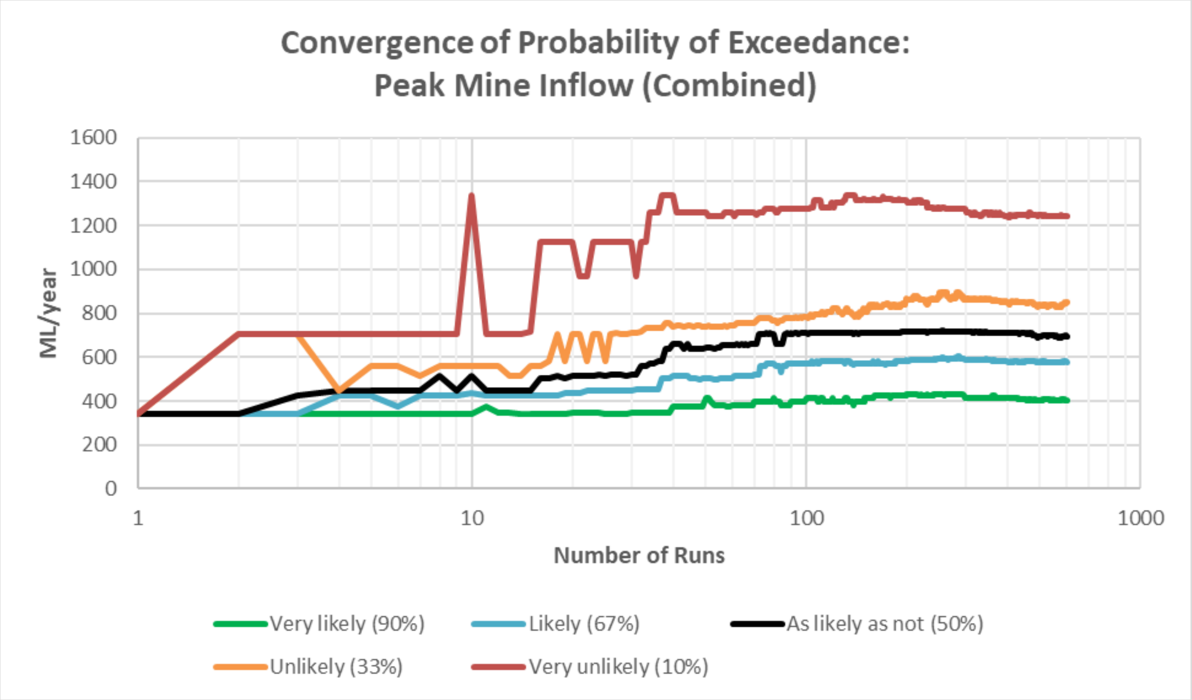


Figure 30: Change in peak mine inflow percentiles with number of model runs.

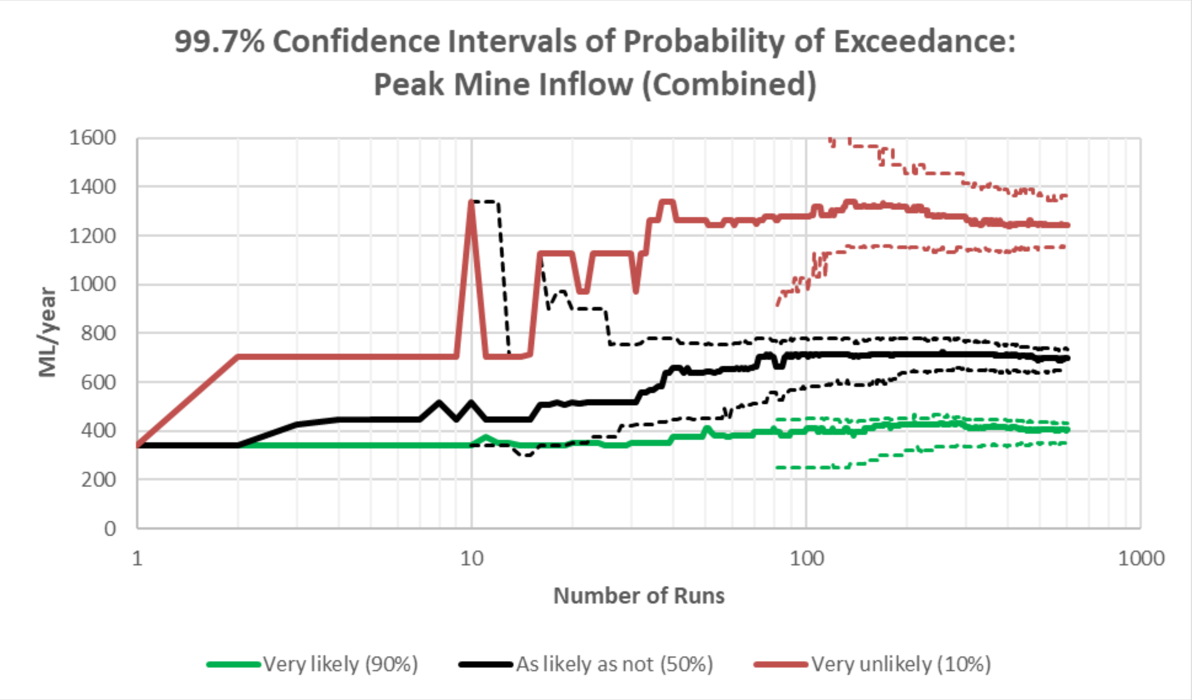


Figure 31: 99.7% confidence intervals for peak mine inflow percentiles.

Peak baseflow impact / enhanced leakage for Tooloombah Creek

Figure 32 and Figure 33 show the change in percentiles of peak baseflow impact / enhanced leakage for Tooloombah Creek with respect to the number of runs evaluated. The 99.7% confidence intervals indicate that the reported values are within 28.03 ML/year of the true values with high probability.

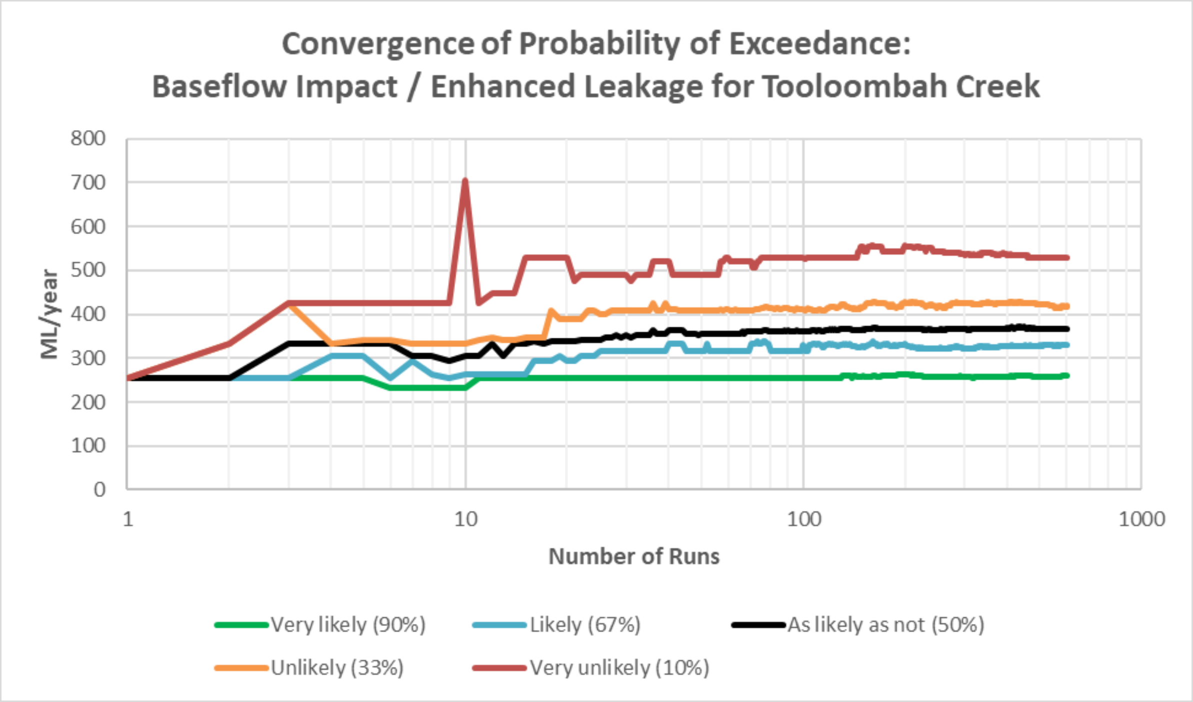


Figure 32: Change in peak Tooloombah Creek baseflow impact / enhanced leakage percentiles with number of model runs.

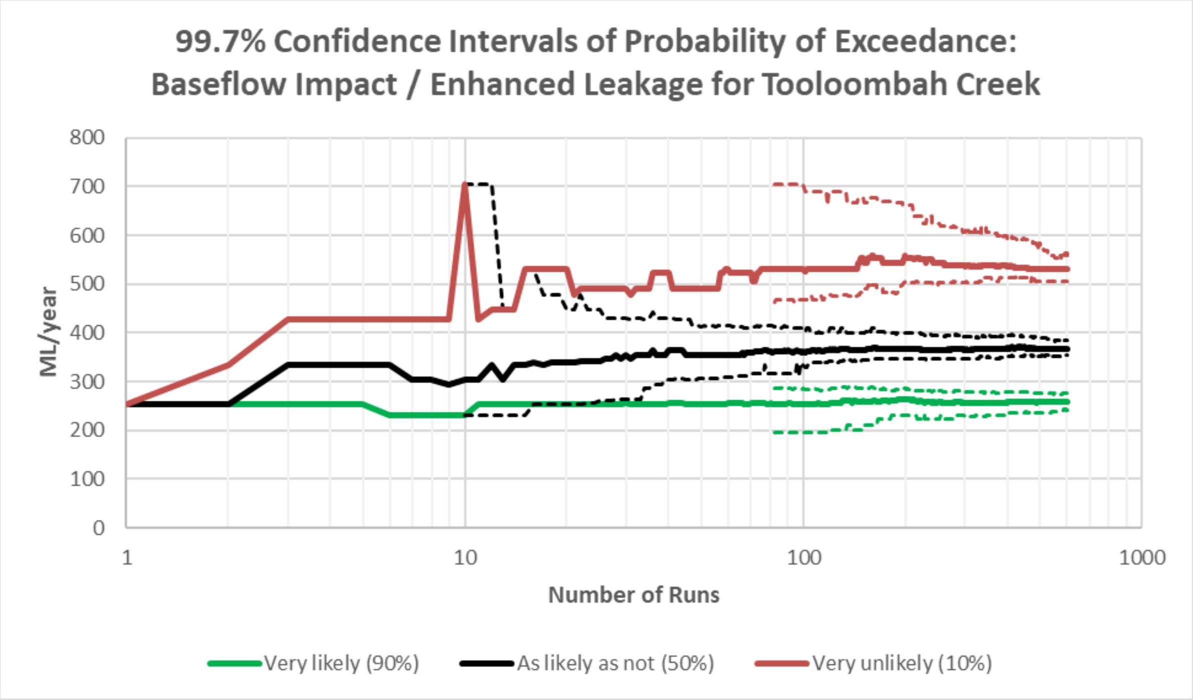


Figure 33: 99.7% confidence intervals for peak Tooloombah Creek baseflow impact / enhanced leakage percentiles.

Peak baseflow impact / enhanced leakage for Styx River

Figure 34 and Figure 35 show the change in percentiles of peak baseflow impact / enhanced leakage for Styx River with respect to the number of runs evaluated. The 99.7% confidence intervals indicate that the reported values are within 1.65 ML/year of the true values with high probability.

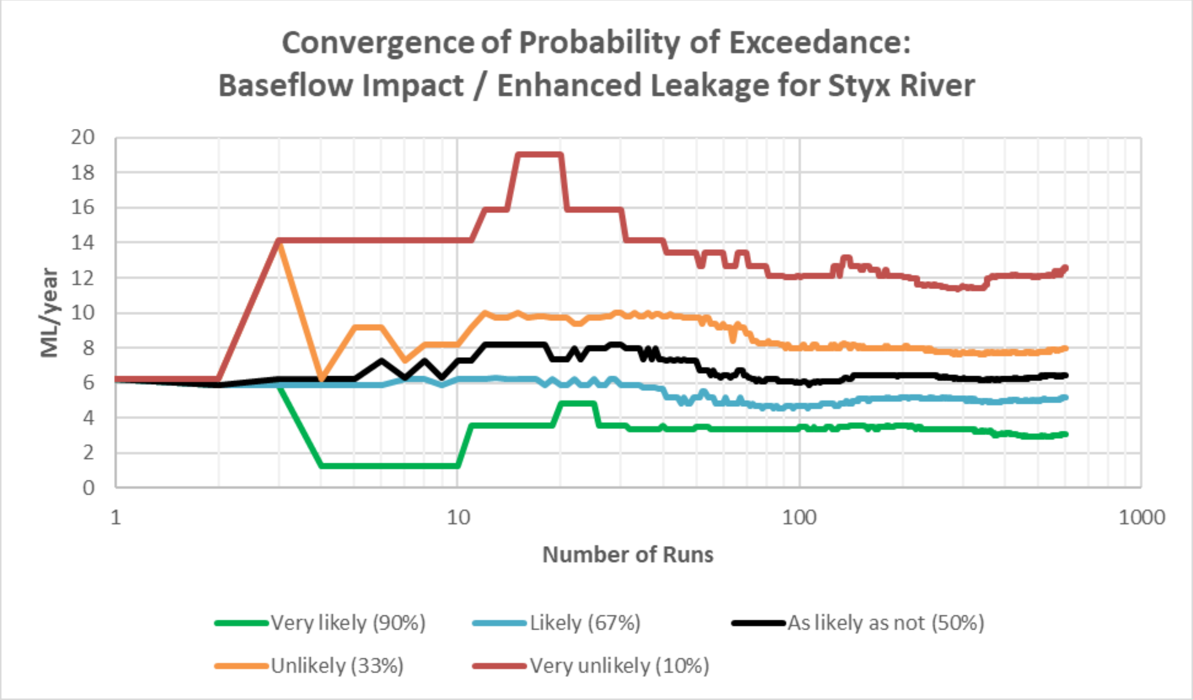


Figure 34: Change in peak Styx River baseflow impact / enhanced leakage percentiles with number of model runs.

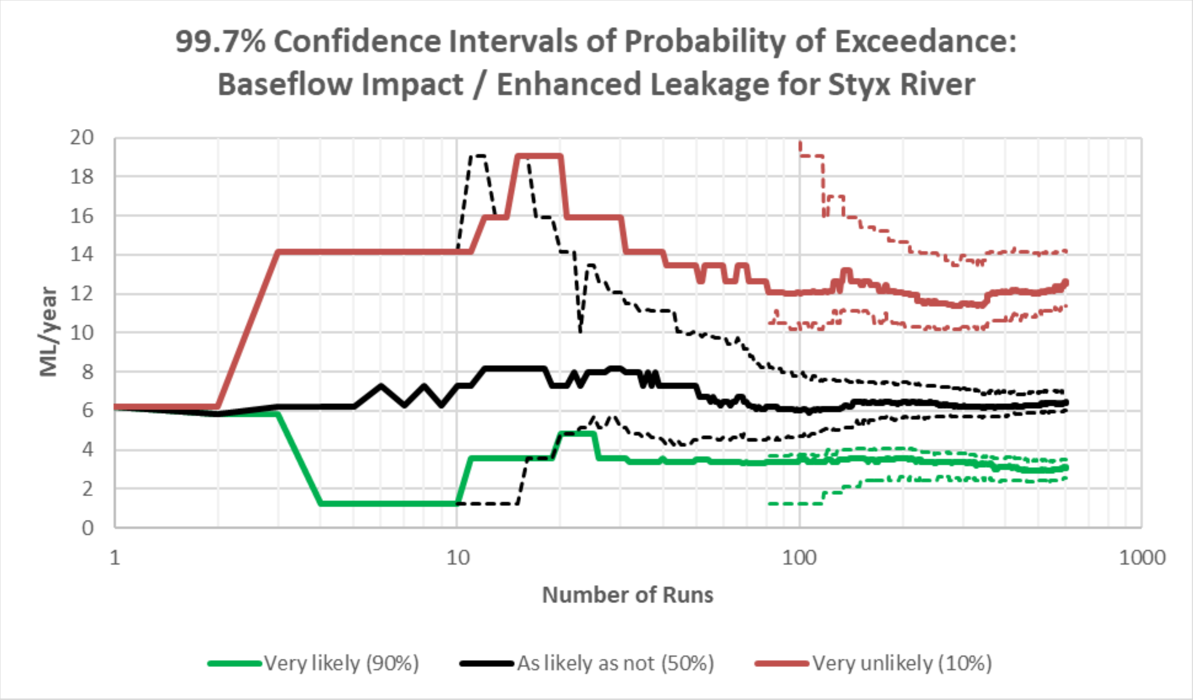


Figure 35: 99.7% confidence intervals for peak Styx River baseflow impact / enhanced leakage percentiles.

Peak baseflow impact / enhanced leakage for Deep Creek

Figure 36 and Figure 37 show the change in percentiles of peak baseflow impact / enhanced leakage for Deep Creek with respect to the number of runs evaluated. The 99.7% confidence intervals indicate that the reported values are within 63.89 ML/year of the true values with high probability.

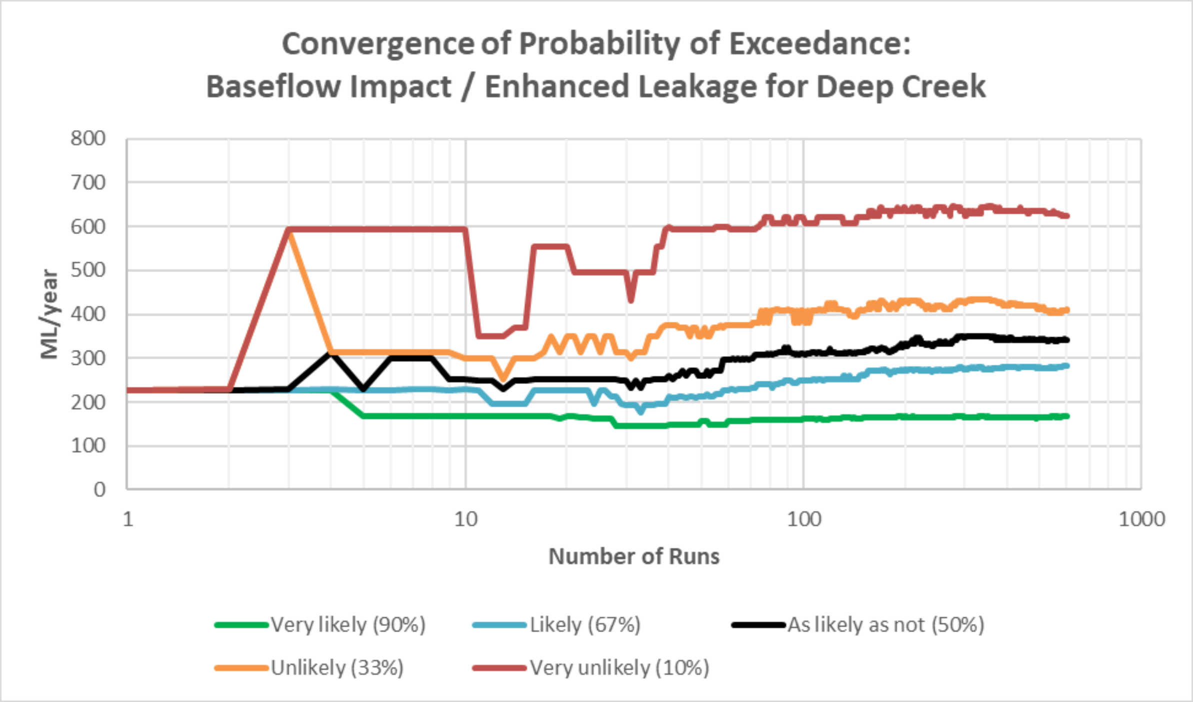


Figure 36: Change in peak Deep Creek baseflow impact / enhanced leakage percentiles with number of model runs.

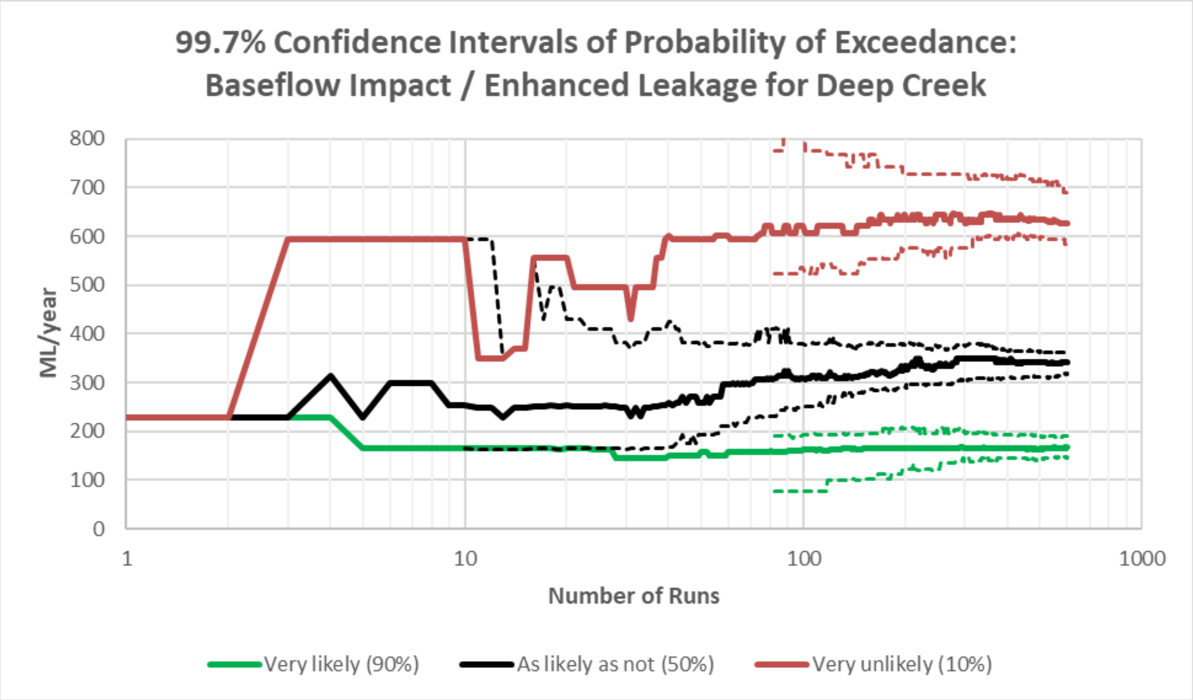


Figure 37: 99.7% confidence intervals for peak Deep Creek baseflow impact / enhanced leakage percentiles.

Peak baseflow impact / enhanced leakage for Mamelon Creek

Figure 38 and Figure 39 show the change in percentiles of peak baseflow impact / enhanced leakage for Mamelon Creek with respect to the number of runs evaluated. The 99.7% confidence intervals indicate that the reported values are within 0.32 ML/year of the true values with high probability.

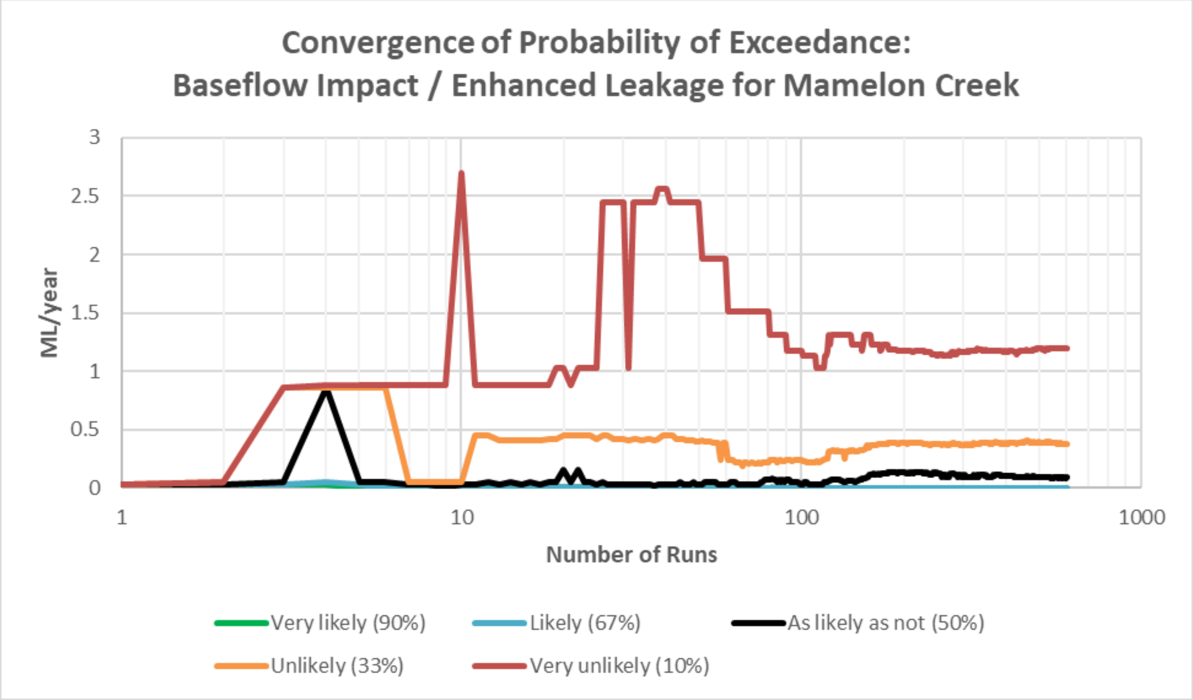


Figure 38: Change in peak Mamelon Creek baseflow impact / enhanced leakage percentiles with number of model runs.

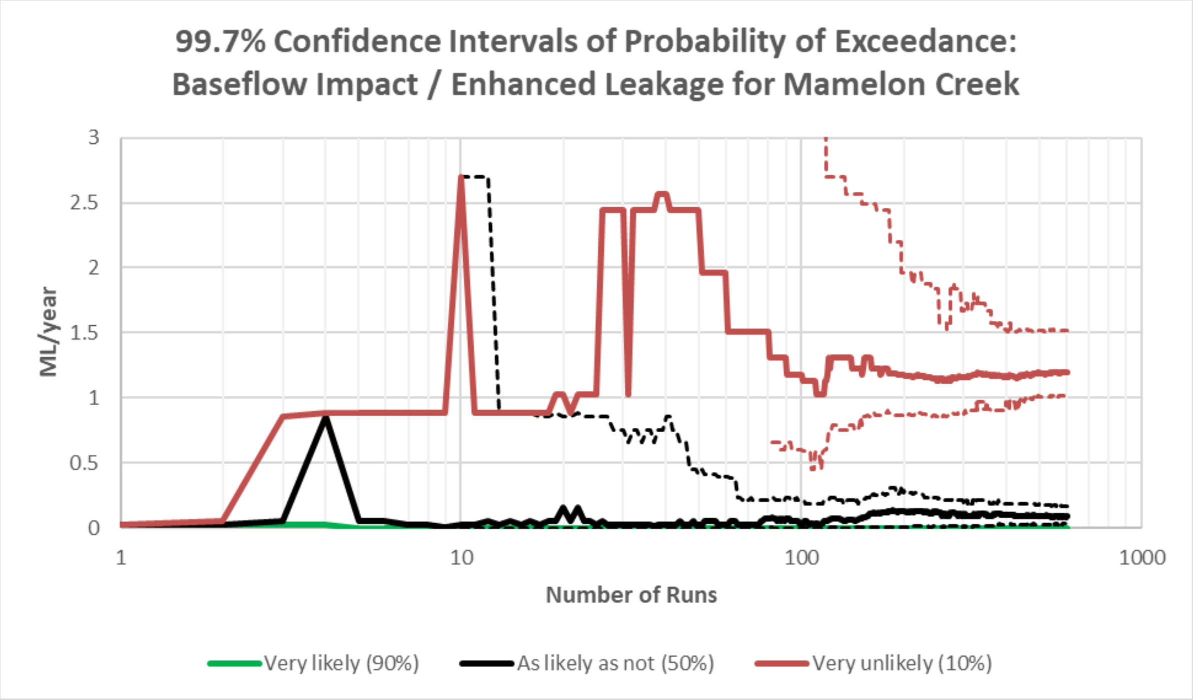


Figure 39: 99.7% confidence intervals for peak Mamelon Creek baseflow impact / enhanced leakage percentiles.

References

Doherty, J., 2015. *Calibration and Uncertainty Analysis for Complex Environmental Models*. Watermark Numerical Computing, Brisbane, Australia. ISBN: 978-0-9943786-0-6.

Doherty, J., 2016. PLPROC: A parameter list processor. Software manual.

HydroAlgorithmics, 2019. AlgoCompute web site, https://www.algocompute.com/. Accessed 27 March 2020.

Merrick, D. and Merrick, N., 2015. AlgoMesh: A new software tool for building unstructured grid models. In *Proc. MODFLOW and More*, Golden, Colorado.

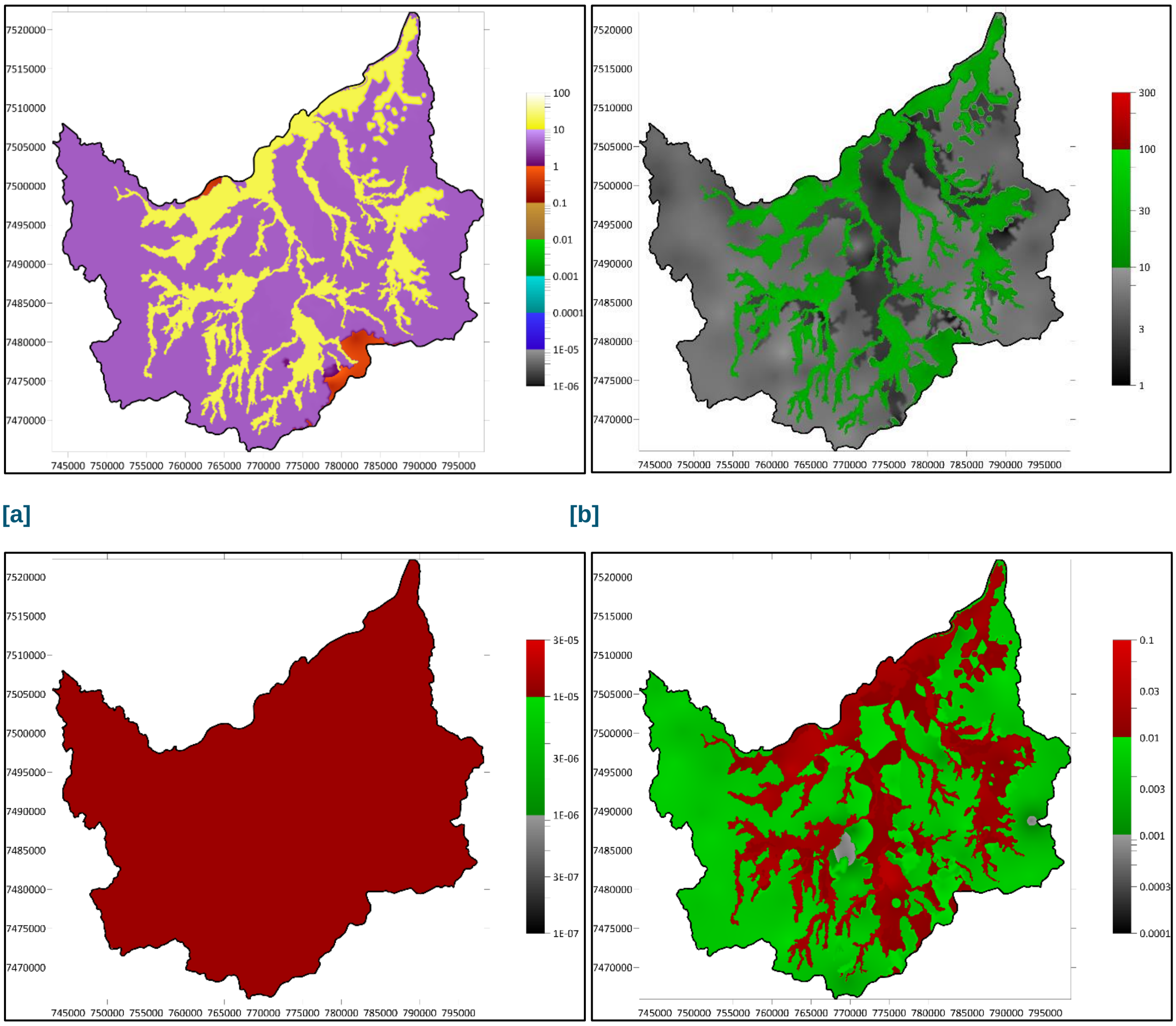
Merrick, D., 2017. AlgoCompute: Large-scale calibration and uncertainty analysis made easy in the cloud. In *Proc. MODFLOW and More*, Golden, Colorado.

Miller, K.L., Berg, S.J., Davison, J.H., Sudicky, E.A., Forsyth, P.A., 2018. Efficient uncertainty quantification in fully-integrated surface and subsurface hydrologic simulations. *Advances in Water Resources*, Volume 111, pp. 381-394.

Mood, A.M., Graybill, F.A., Boes, D.C., 1974. *Introduction to the Theory of Statistics, 3rd Edition*. Mcgraw-Hill, Inc. ISBN: 978-0-07-042864-5.

Vrugt, J.A., ter Braak, C J.F., Diks, C.G.H., Higdon, D., Robinson, B.A., and Hyman, J.M., 2009. Accelerating Markov chain Monte Carlo simulation by differential evolution with self-adaptive randomized subspace sampling. *International Journal of Nonlinear Sciences and Numerical Simulation*, Volume 10, Issue 3, pp. 273-290.

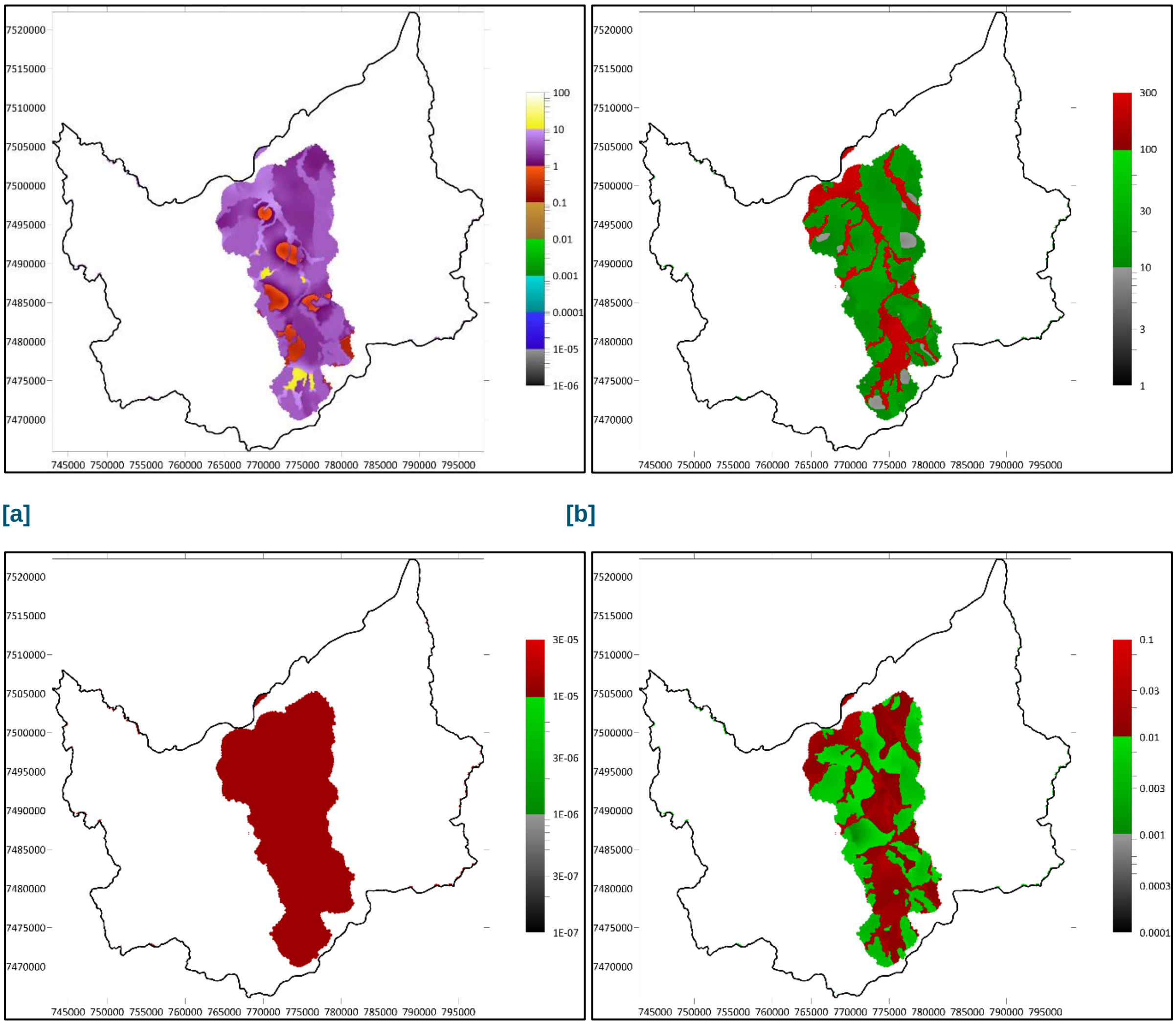
ATTACHMENT 12
PILOT POINT PROPERTIES SPATIAL PLOTS



[a] **[b]**

[c] **[d]**

Layer 2 - Hydraulic (K_H & K_H/K_V Ratio) and Storage (S_s and S_y) Properties
[a] = K_H Horizontal Hydraulic Conductivity [m/day]
[b] = K_H/K_V Hydraulic Conductivity Ratio [-]
[c] = S_s Specific Storativity [1/m]
[d] = S_y Specific Yield [-]



[a] [b]

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Layer 3 - Hydraulic (K_H & K_H/K_V Ratio) and Storage (S_s and S_y) Properties
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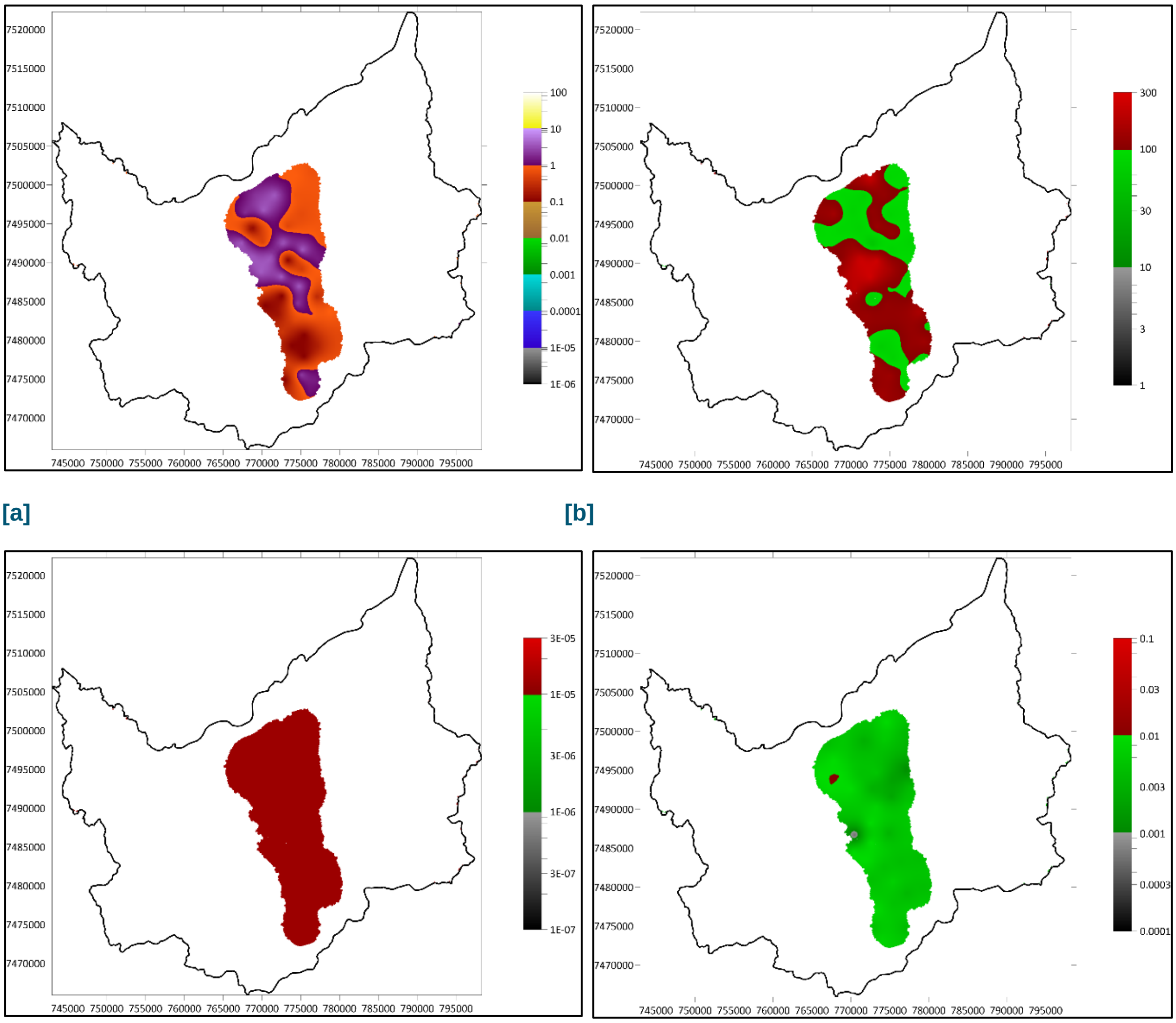

[a] [b]

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Layer 4 - Hydraulic (K_H & K_H/K_V Ratio) and Storage (S_s and S_y) Properties

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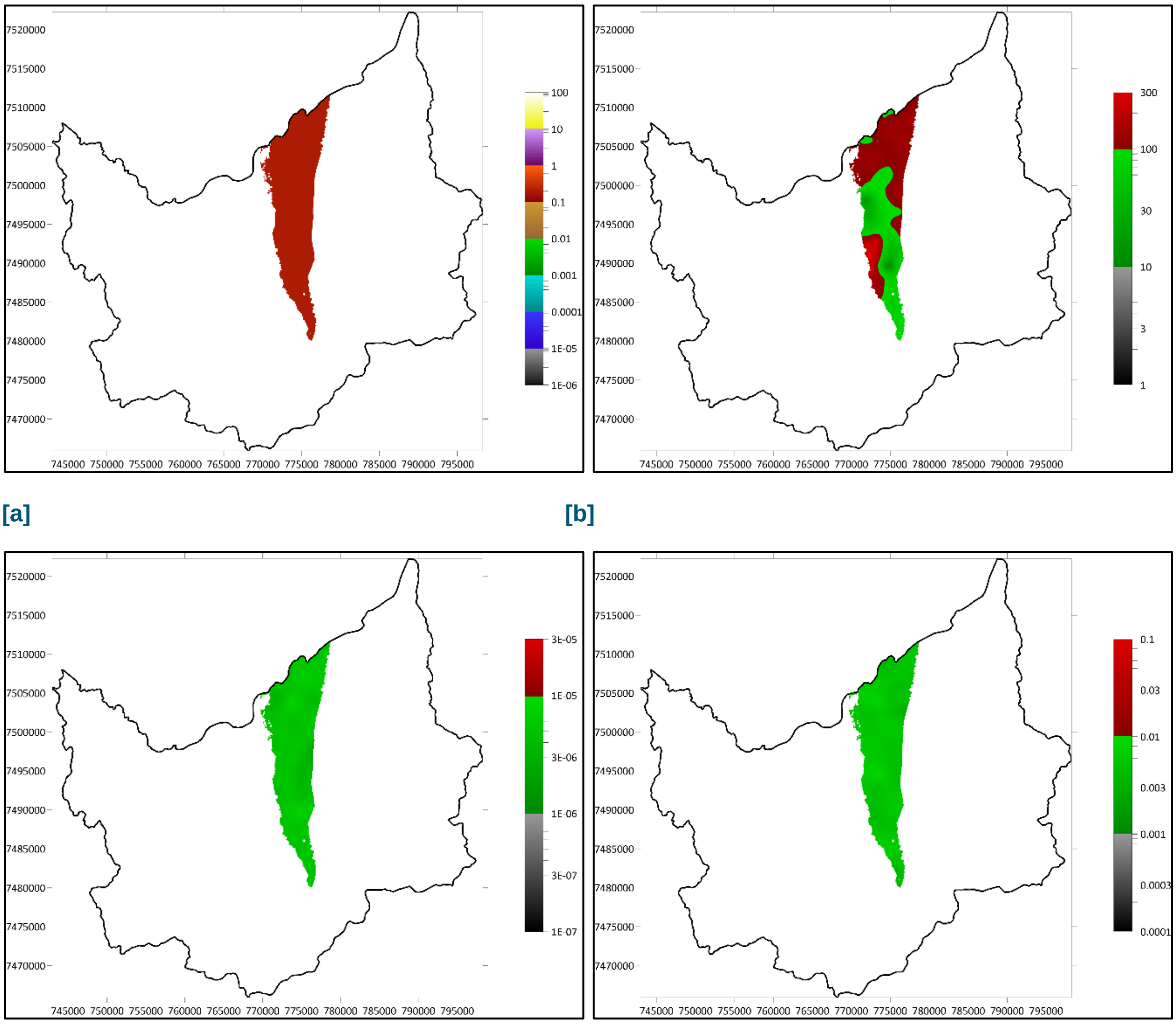

[a] [b]

[c] [d]

Layer 5 - Hydraulic (K_H & K_H/K_V Ratio) and Storage (S_s and S_y) Properties
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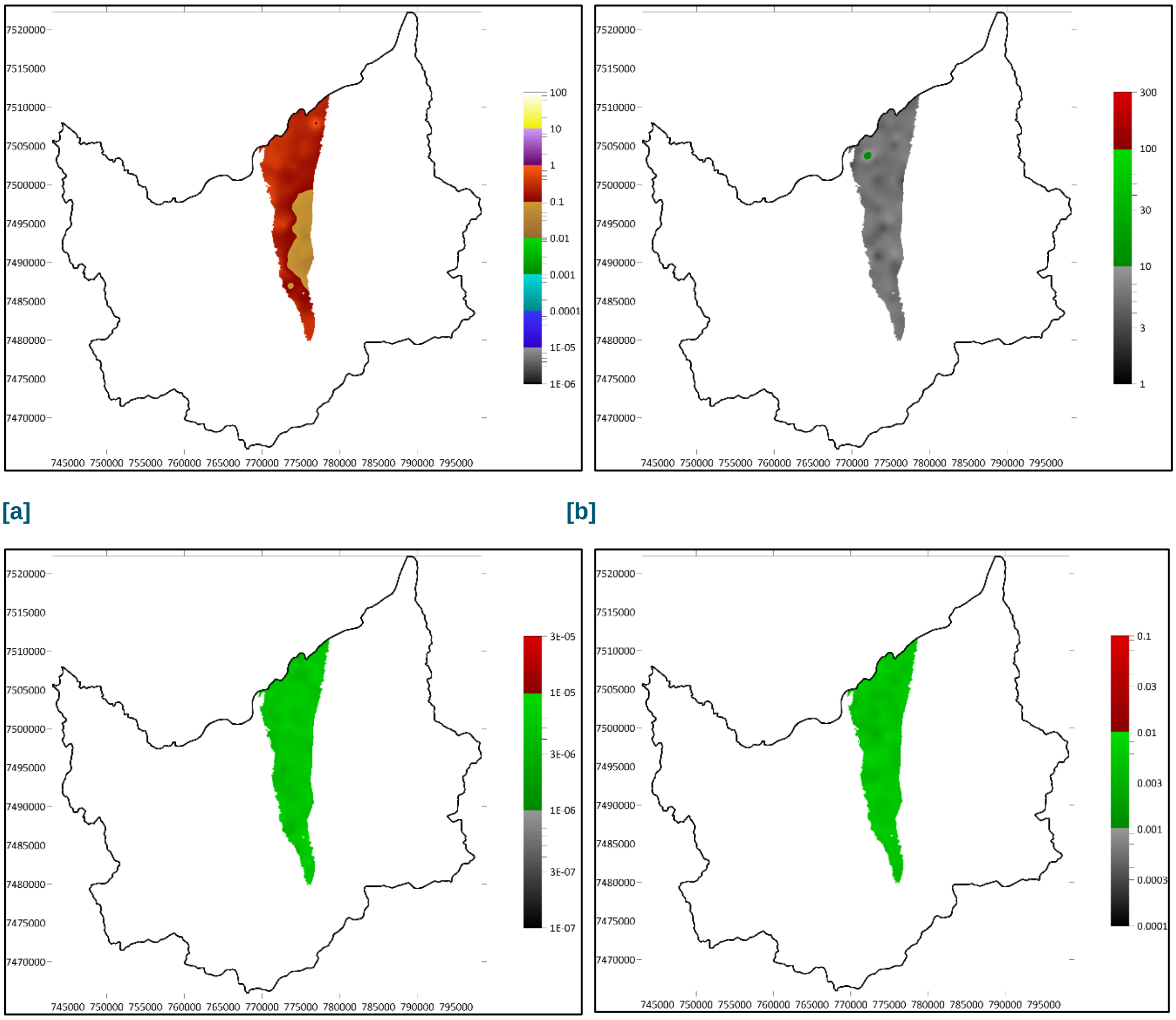

[a] **[b]**

[c] **[d]**

Layer 6 - Hydraulic (K_H & K_H/K_V Ratio) and Storage (S_s and S_y) Properties
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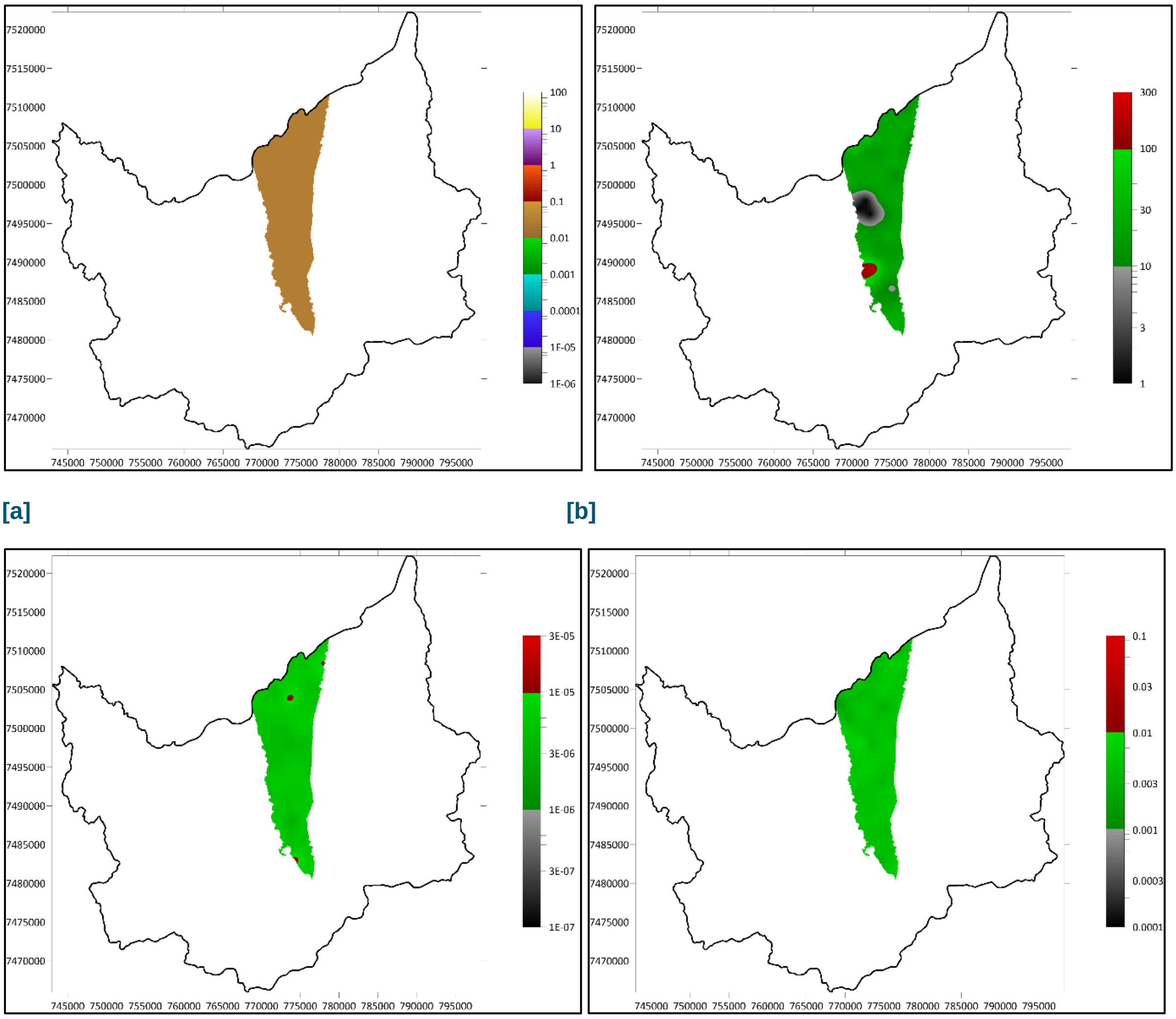
[d] = S_y Specific Yield [-]



[a]

[b]

[c]

[d]

Layer 7 - Hydraulic (K_H & K_H/K_V Ratio) and Storage (S_s and S_y) Properties
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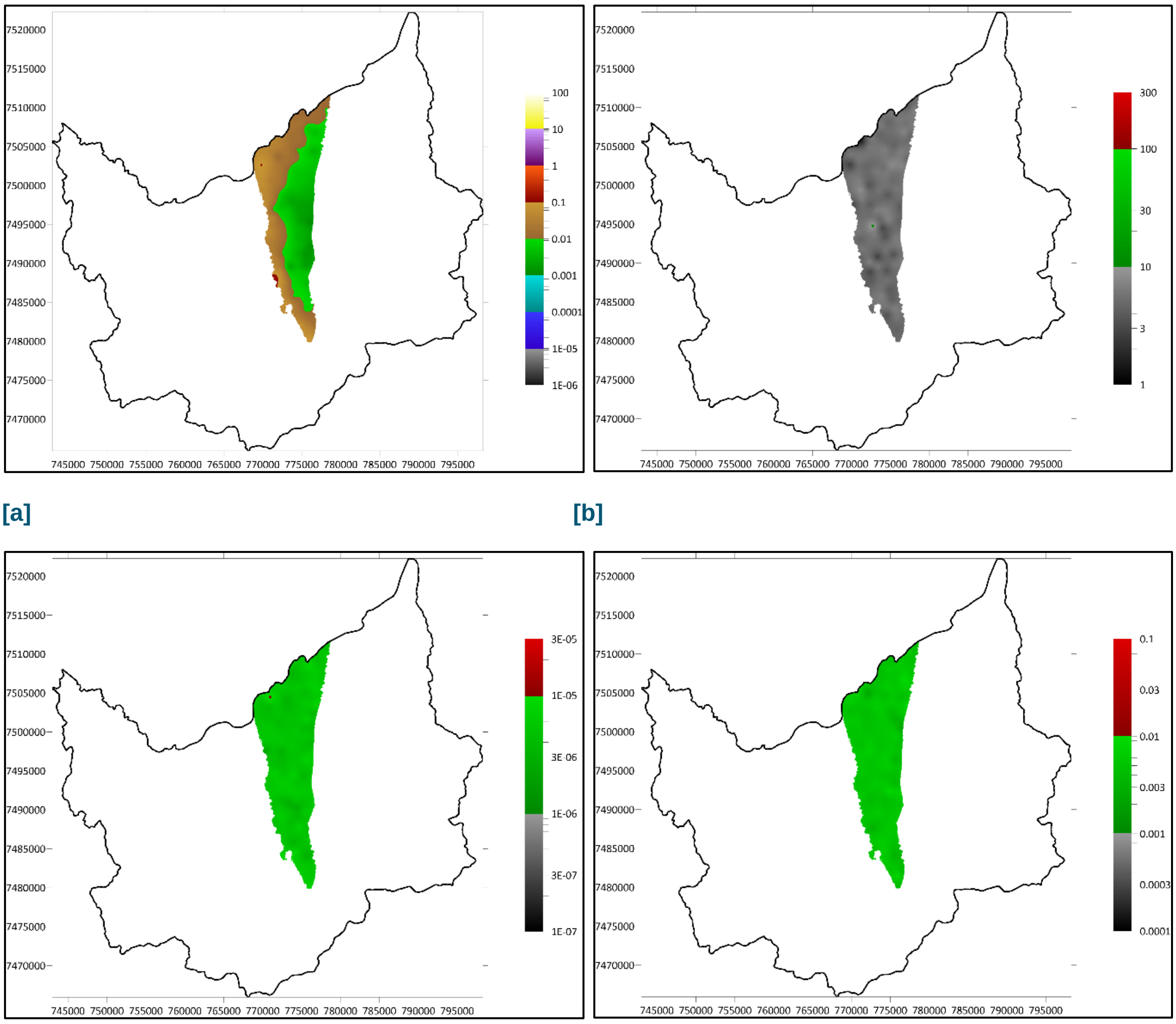

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Layer 8 - Hydraulic (K_H & K_H/K_V Ratio) and Storage (S_s and S_y) Properties
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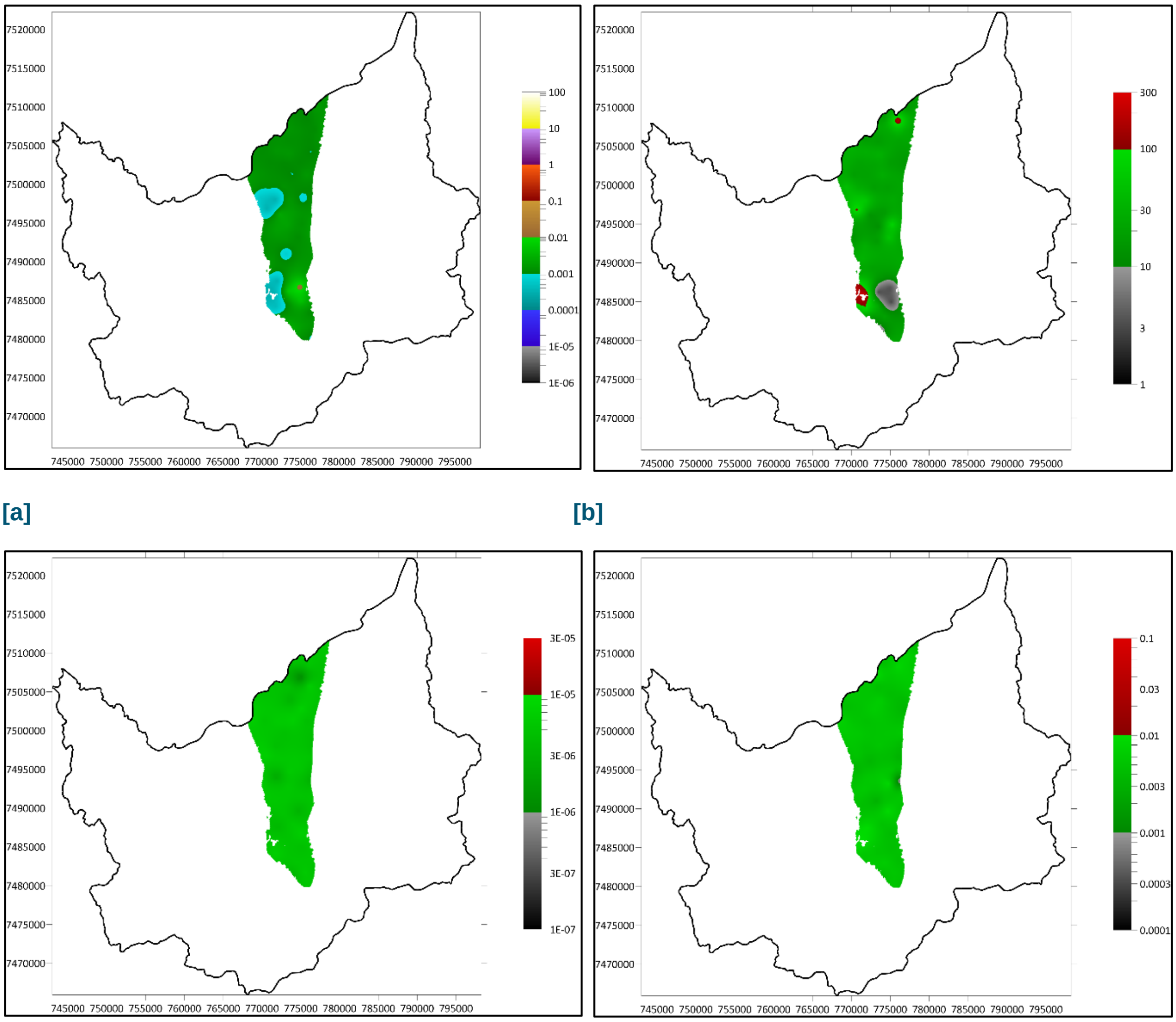

[a] **[b]**

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Layer 9 - Hydraulic (K_H & K_H/K_V Ratio) and Storage (S_s and S_y) Properties
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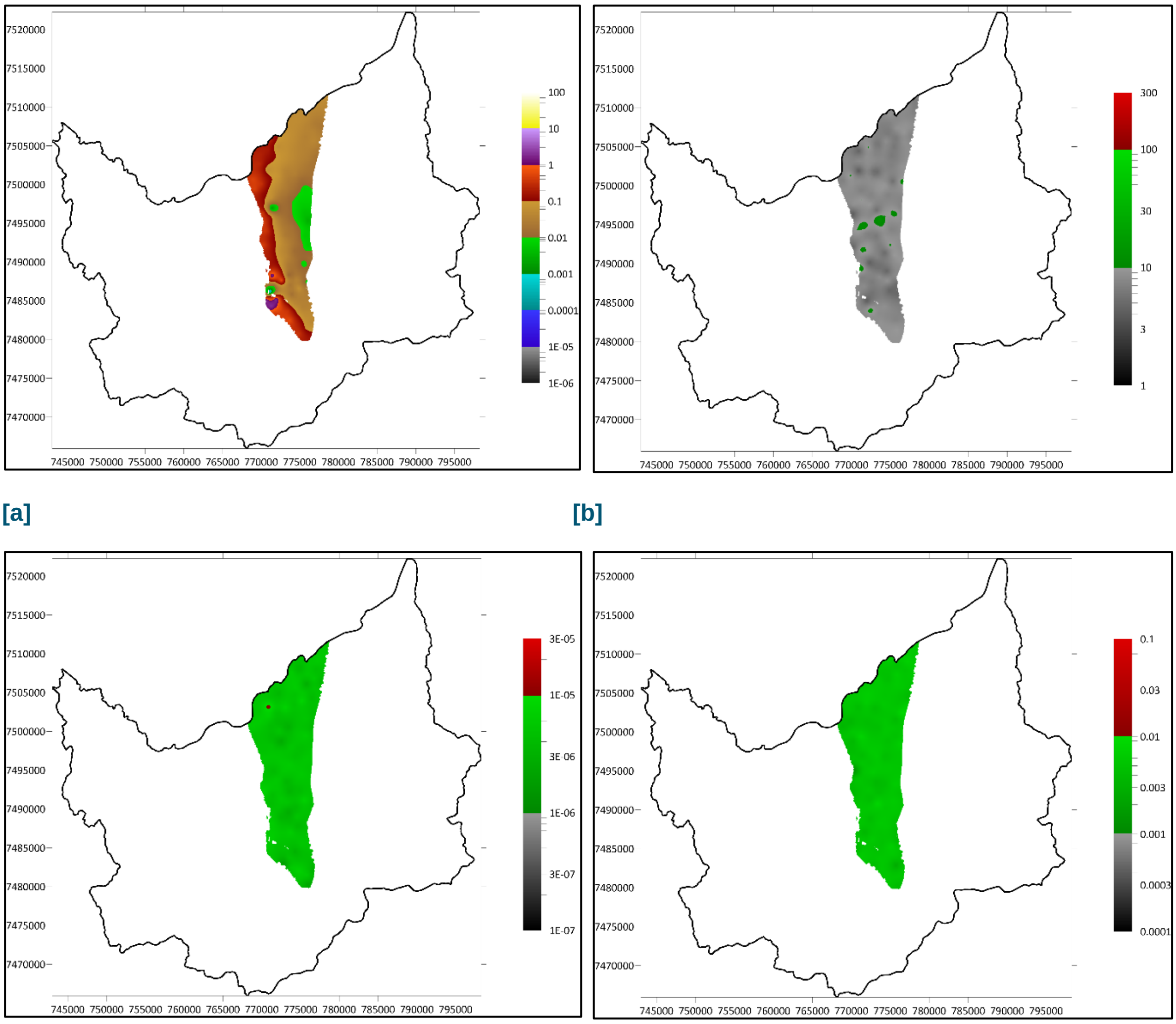

[a] **[b]**

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Layer 10 - Hydraulic (K_H & K_H/K_V Ratio) and Storage (S_s and S_y) Properties
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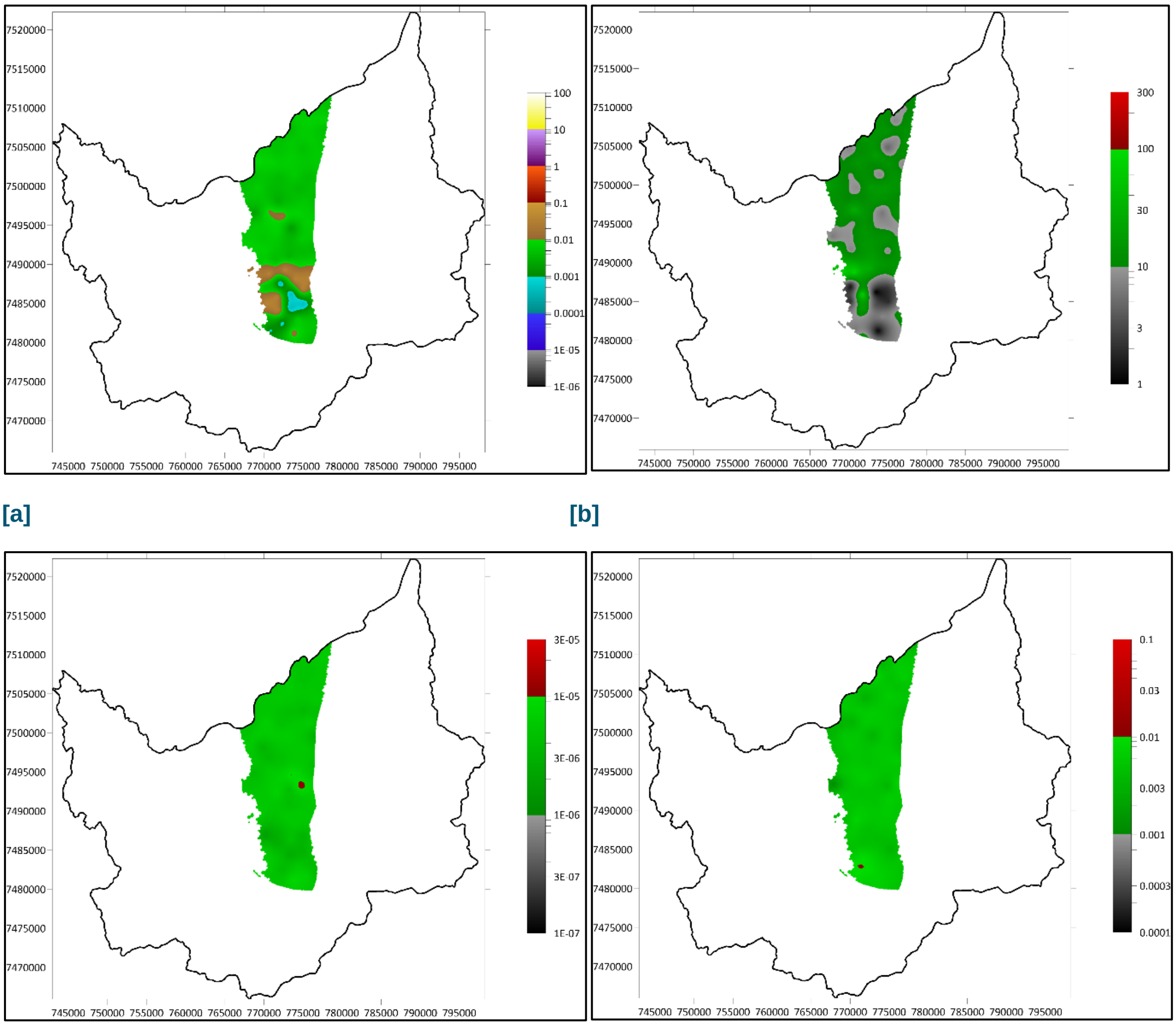

[a] [b]

[c] [d]

Layer 11 - Hydraulic (K_H & K_H/K_V Ratio) and Storage (S_s and S_y) Properties
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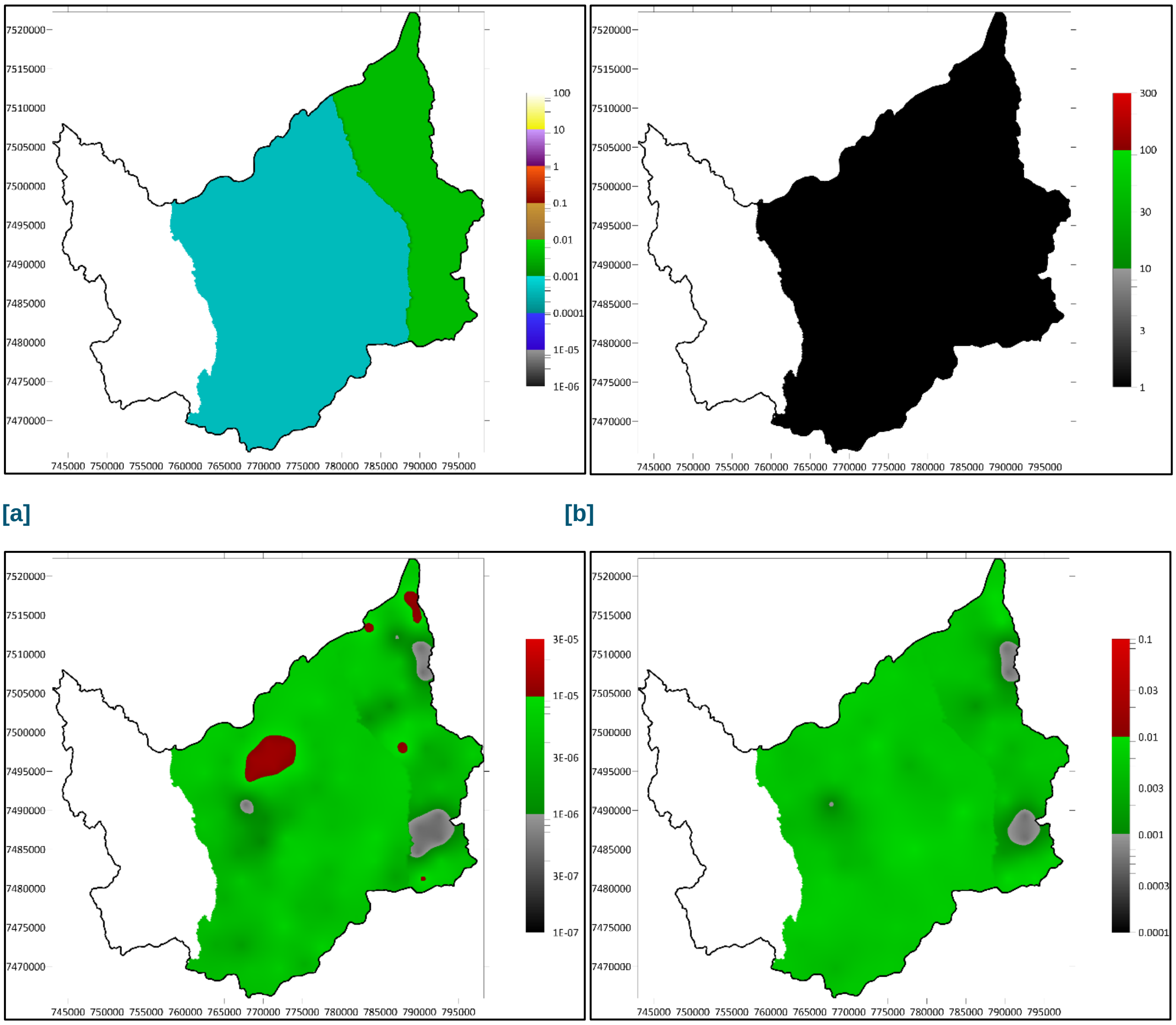
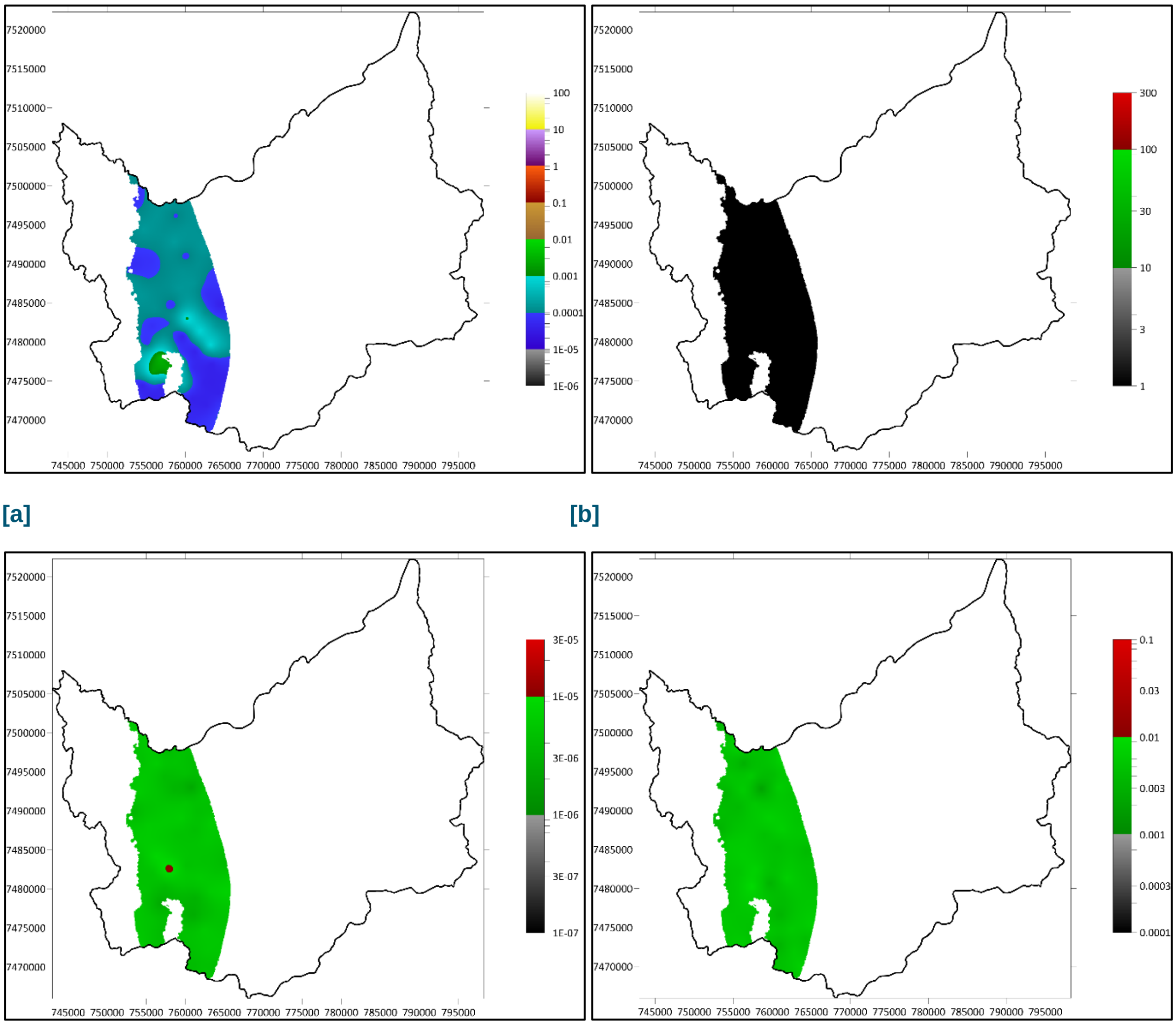
[b] = K_H/K_V Hydraulic Conductivity Ratio [-]
[c] = S_s Specific Storativity [1/m]
[d] = S_y Specific Yield [-]



[a] **[b]**

[c] **[d]**

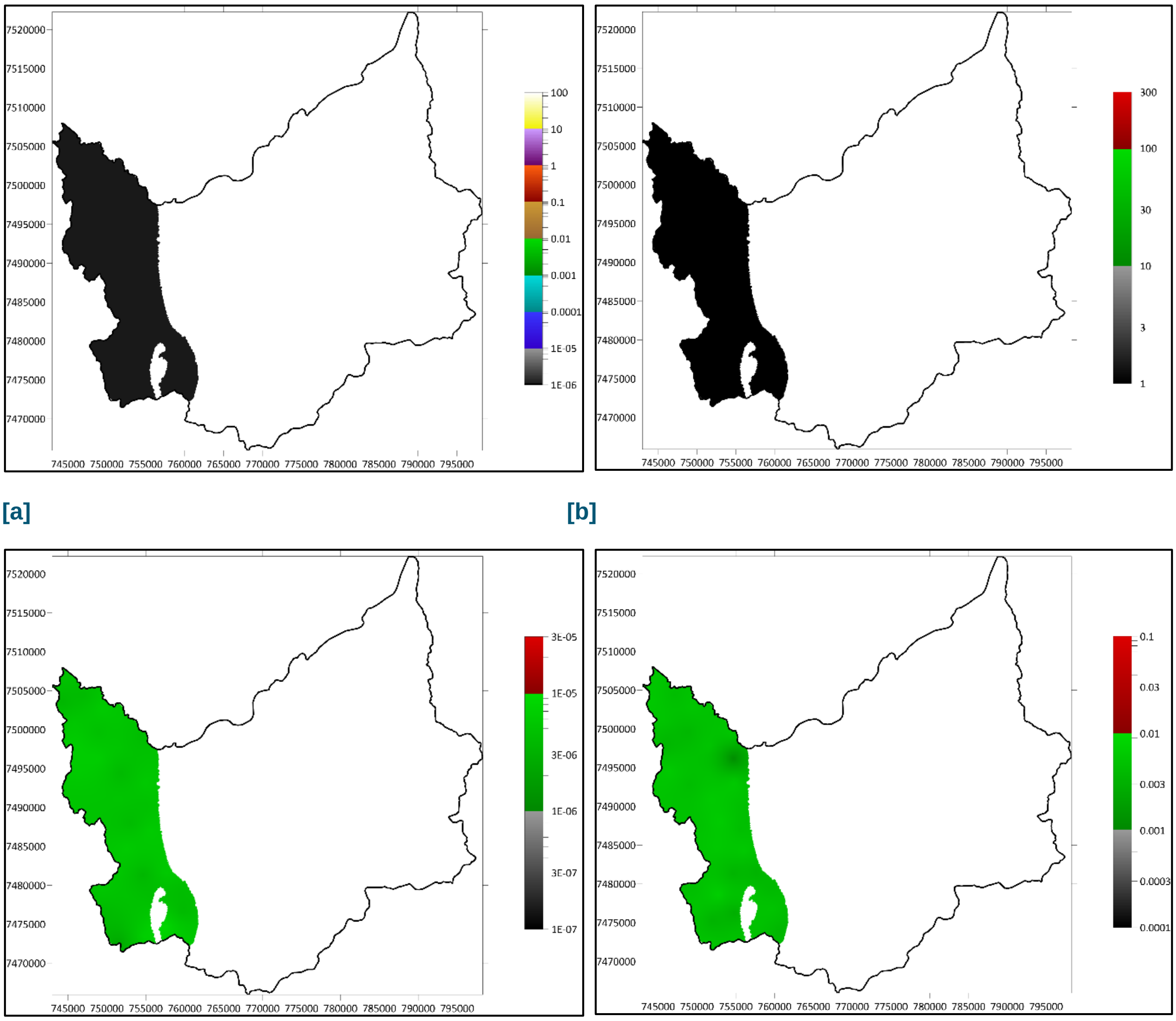
Layer 12 - Hydraulic (K_H & K_H/K_V Ratio) and Storage (S_s and S_y) Properties
[a] = K_H Horizontal Hydraulic Conductivity [m/day]
[b] = K_H/K_V Hydraulic Conductivity Ratio [-]
[c] = S_s Specific Storativity [1/m]
[d] = S_y Specific Yield [-]



[a] **[b]**

[c] **[d]**

Layer 13 - Hydraulic (K_H & K_H/K_V Ratio) and Storage (S_s and S_y) Properties
[a] = K_H Horizontal Hydraulic Conductivity [m/day]
[b] = K_H/K_V Hydraulic Conductivity Ratio [-]
[c] = S_s Specific Storativity [1/m]
[d] = S_y Specific Yield [-]

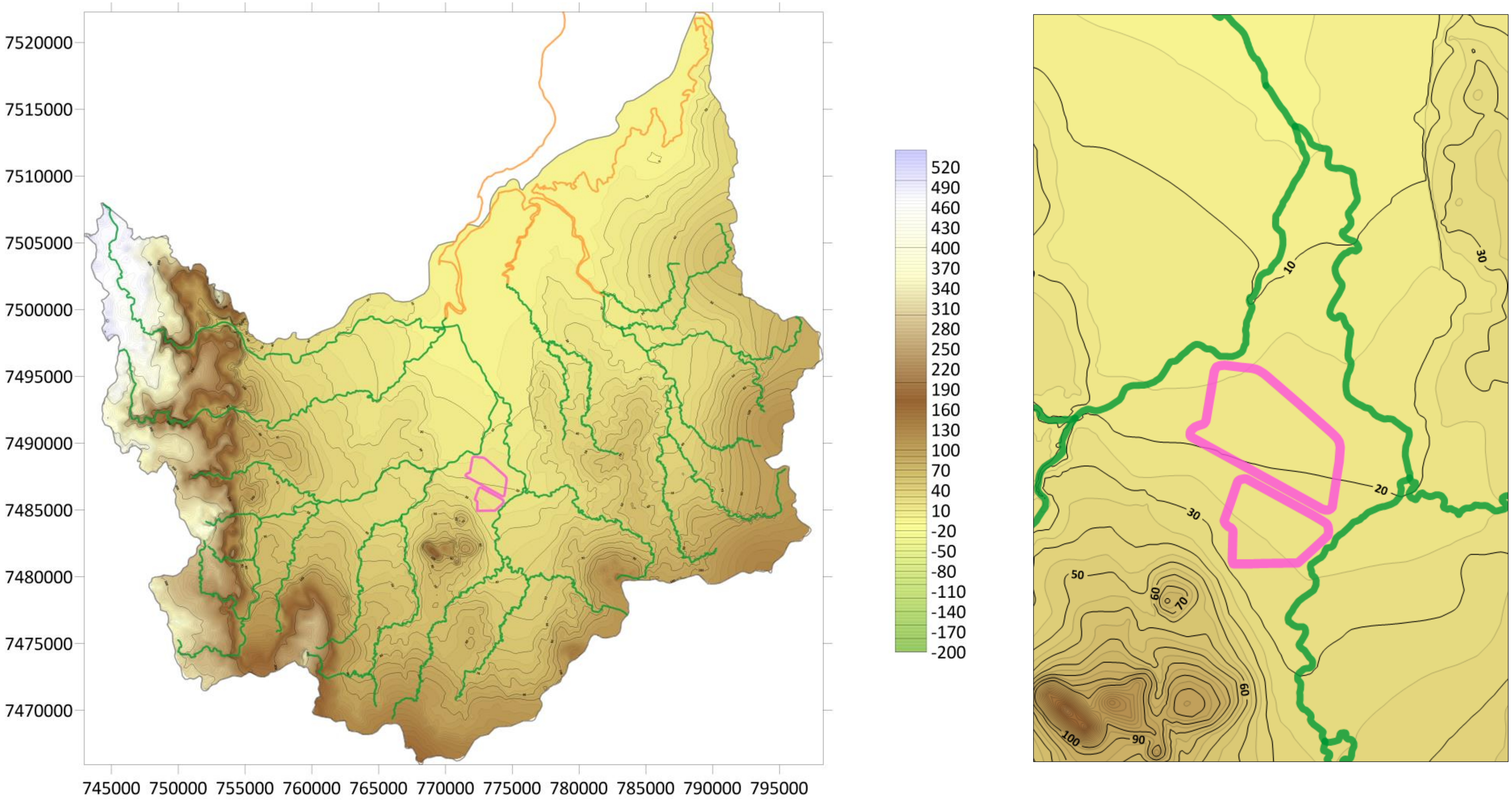


[a] [b]

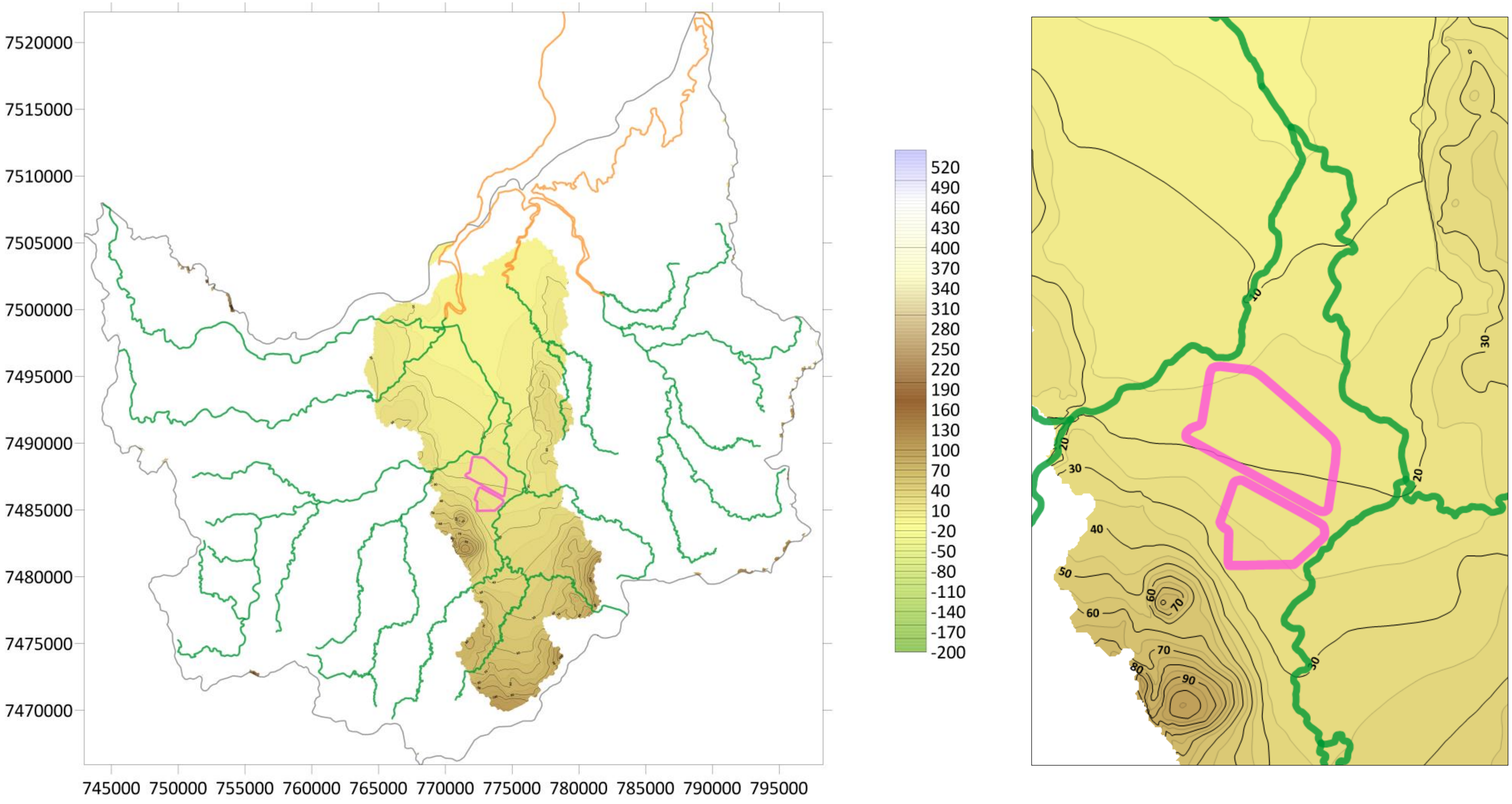
[c] [d]

Layer 14 - Hydraulic (K_H & K_H/K_V Ratio) and Storage (S_s and S_y) Properties
[a] = K_H Horizontal Hydraulic Conductivity [m/day]
[b] = K_H/K_V Hydraulic Conductivity Ratio [-]
[c] = S_s Specific Storativity [1/m]
[d] = S_y Specific Yield [-]

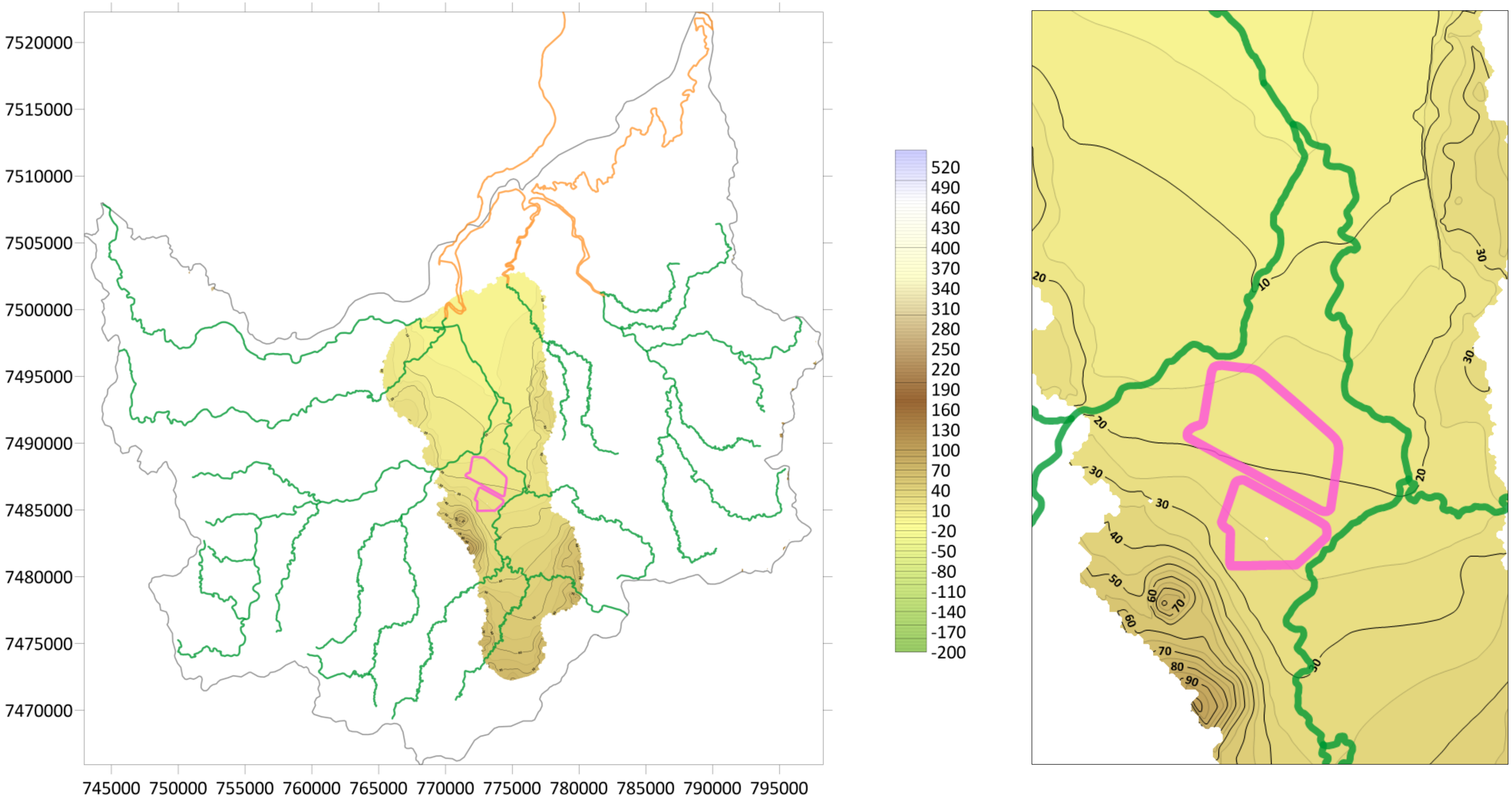
ATTACHMENT 13
MODEL LAYER HEAD PLOTS – END OF CALIBRATION



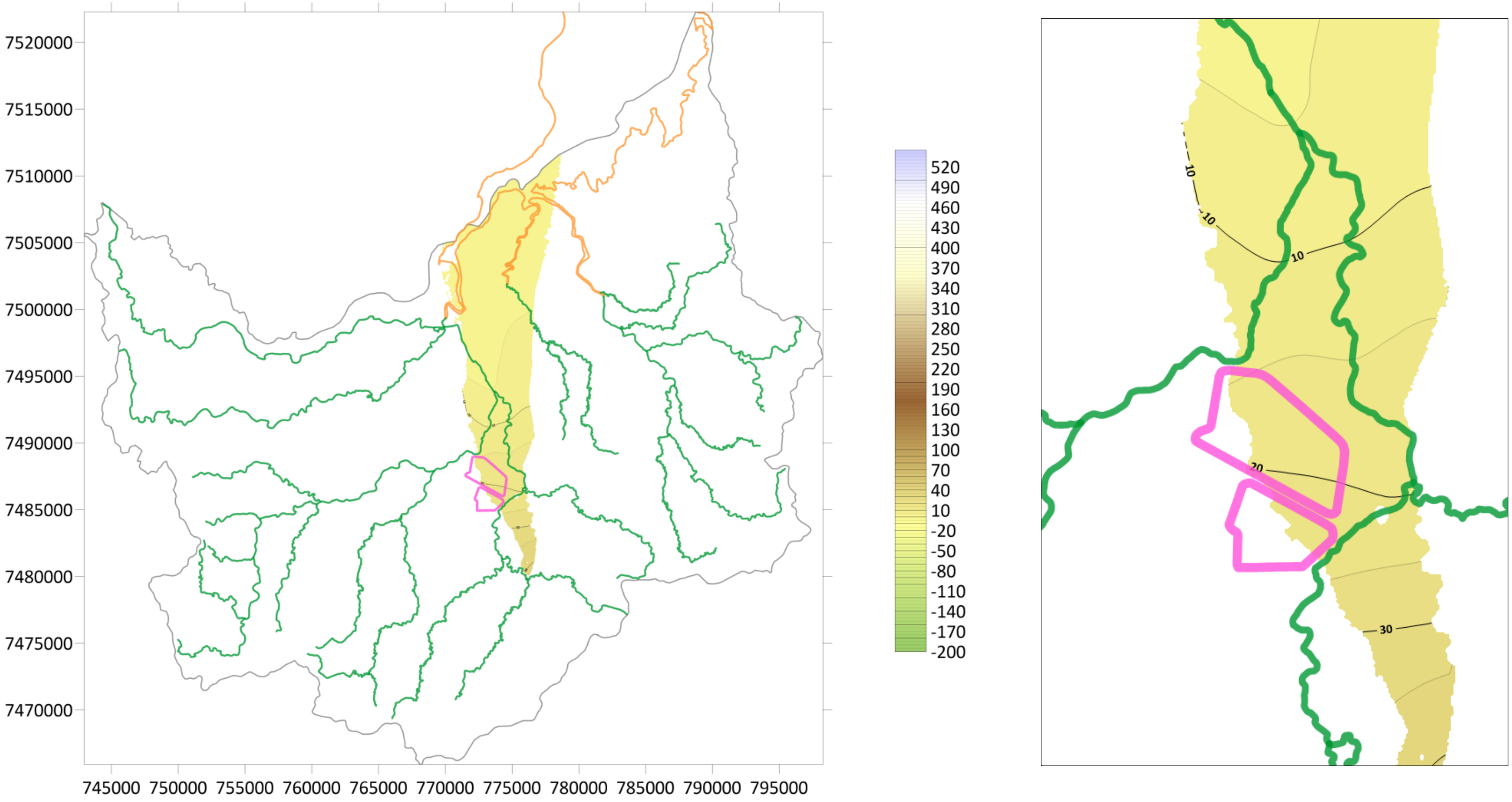
Layer 2 – Groundwater Head Plot (mAHD) – End of Calibration



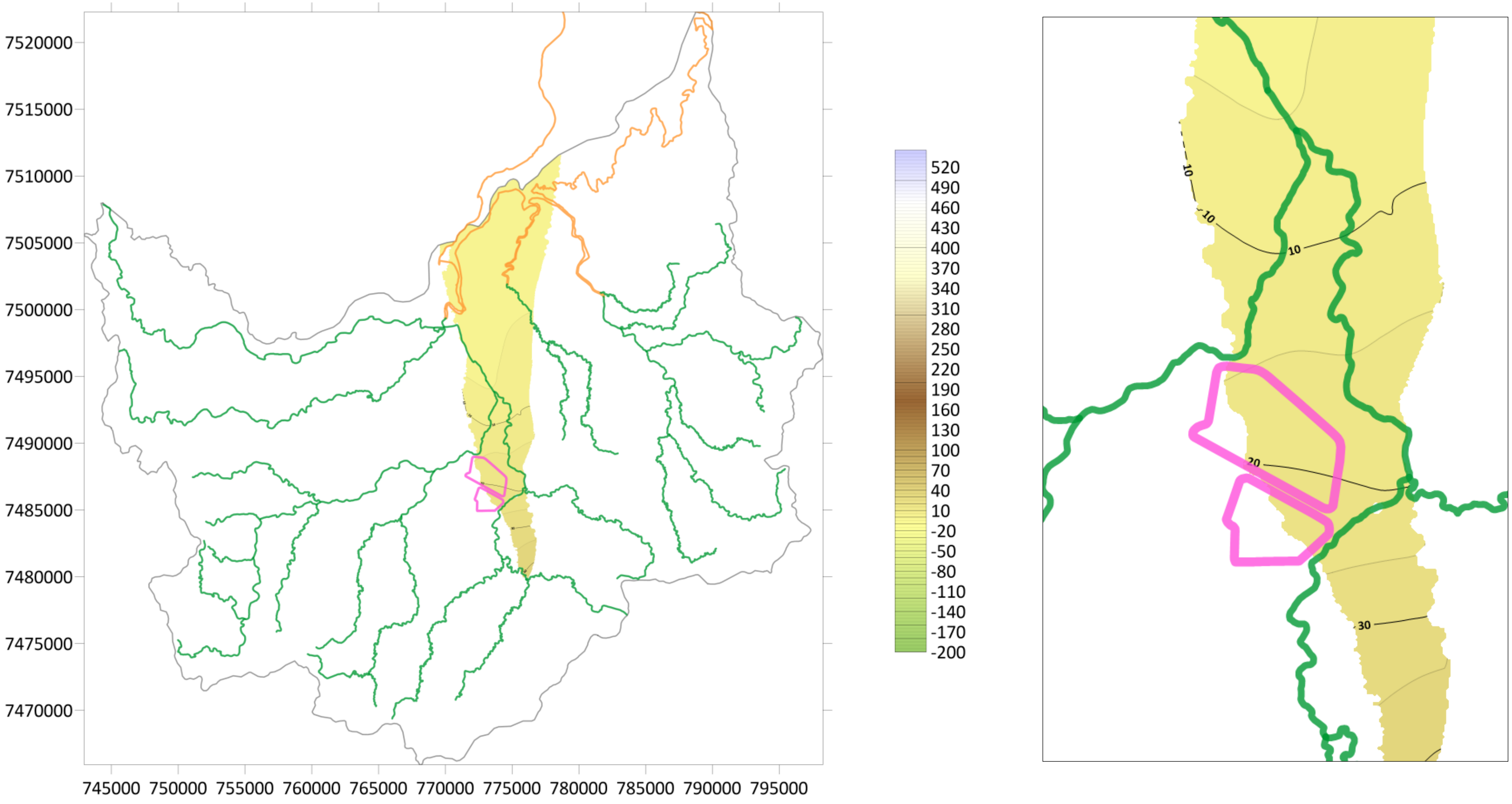
Layer 3 – Groundwater Head Plot (mAHD) – End of Calibration



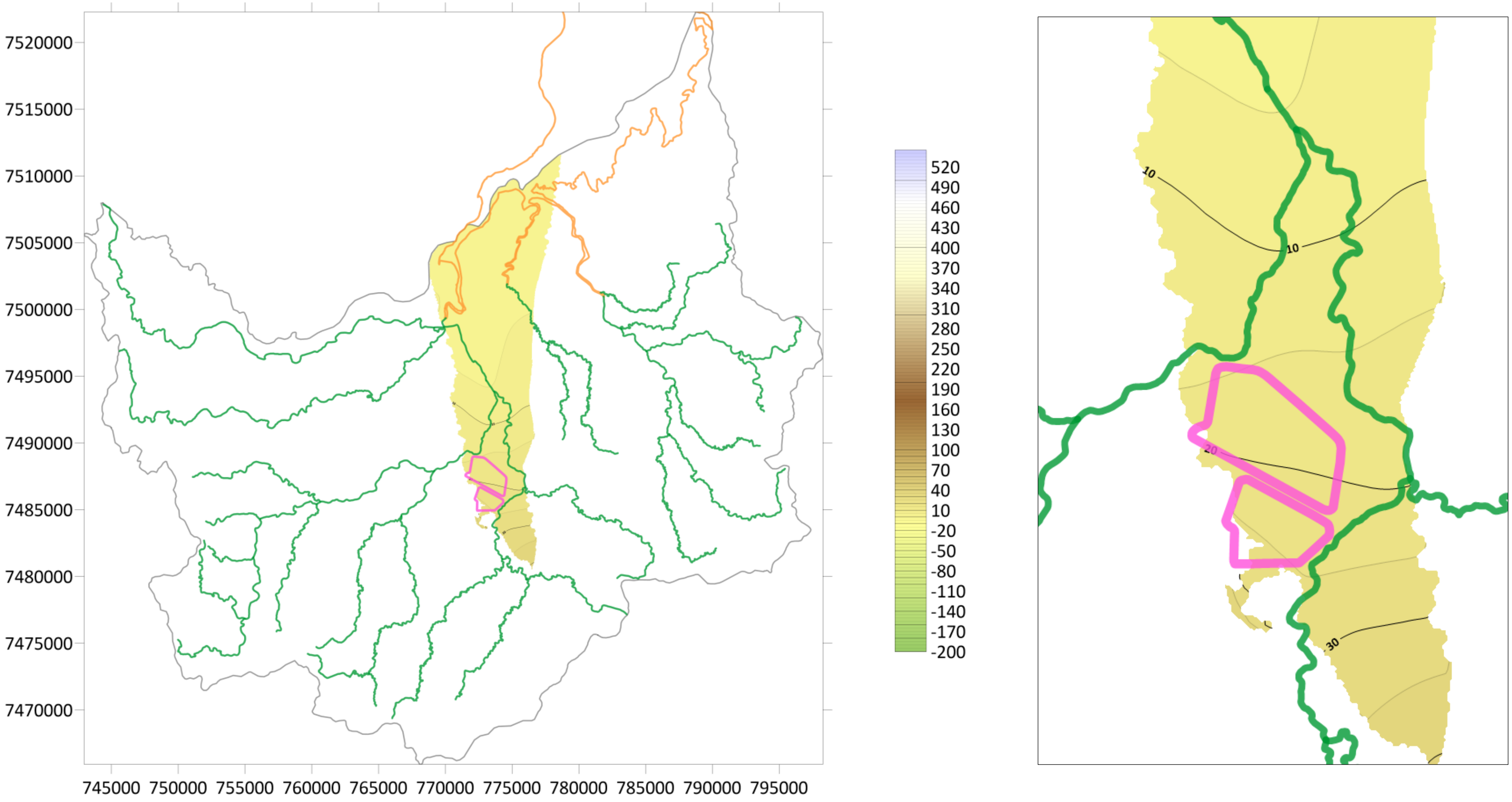
Layer 4 – Groundwater Head Plot (mAHD) – End of Calibration



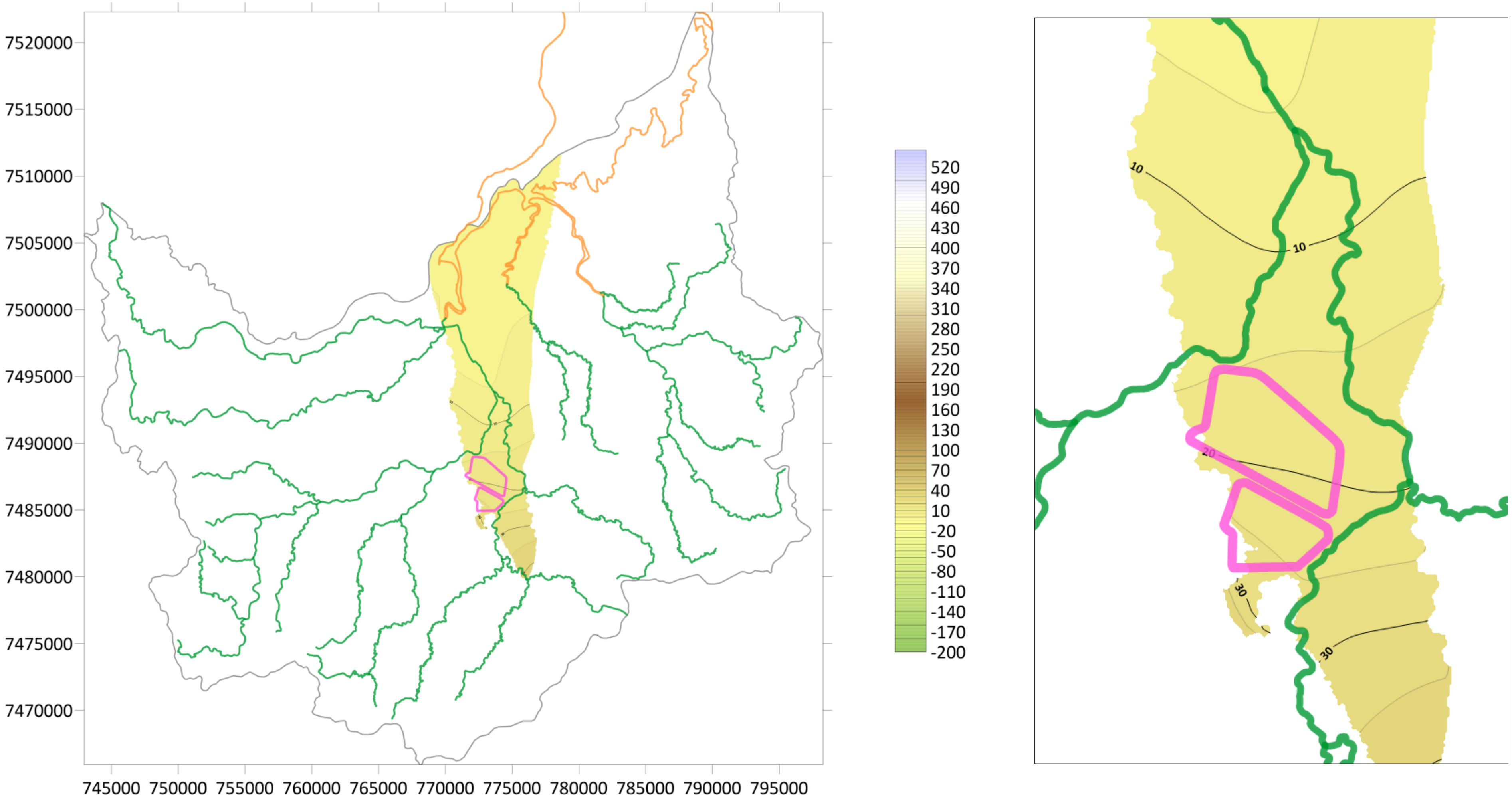
Layer 5 – Groundwater Head Plot (mAHD) – End of Calibration



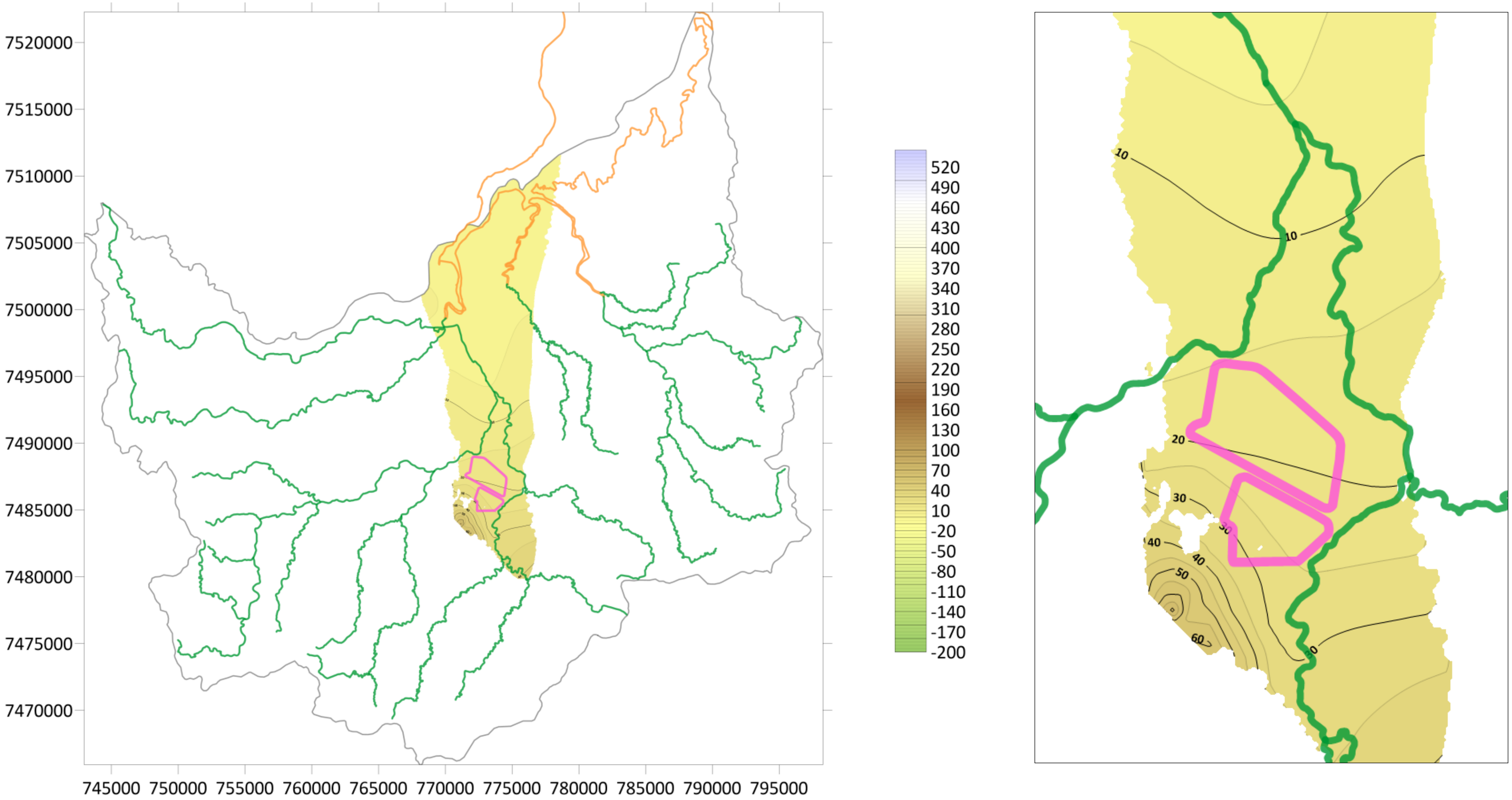
Layer 6 – Groundwater Head Plot (mAHD) – End of Calibration



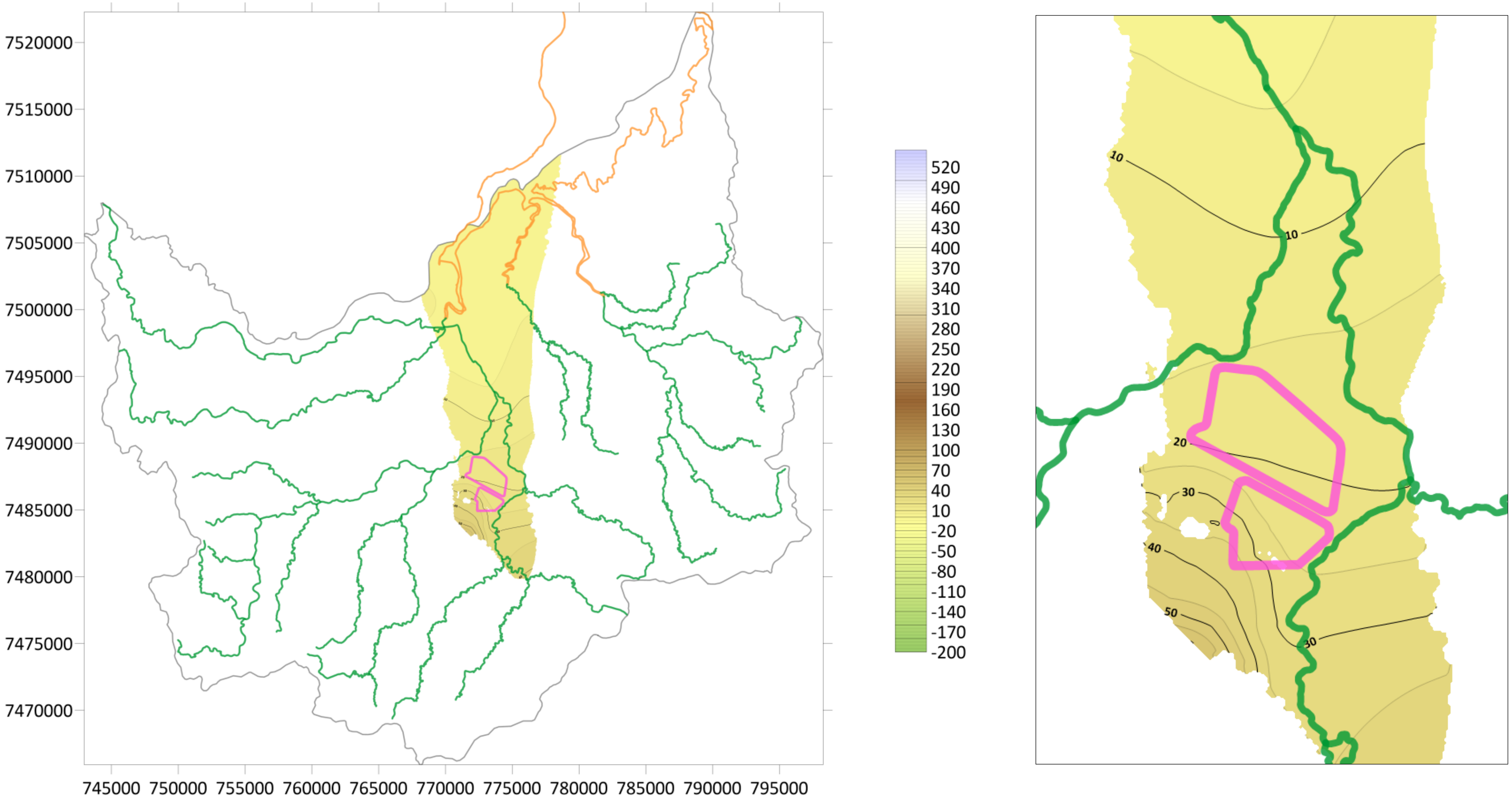
Layer 7 – Groundwater Head Plot (mAHD) – End of Calibration



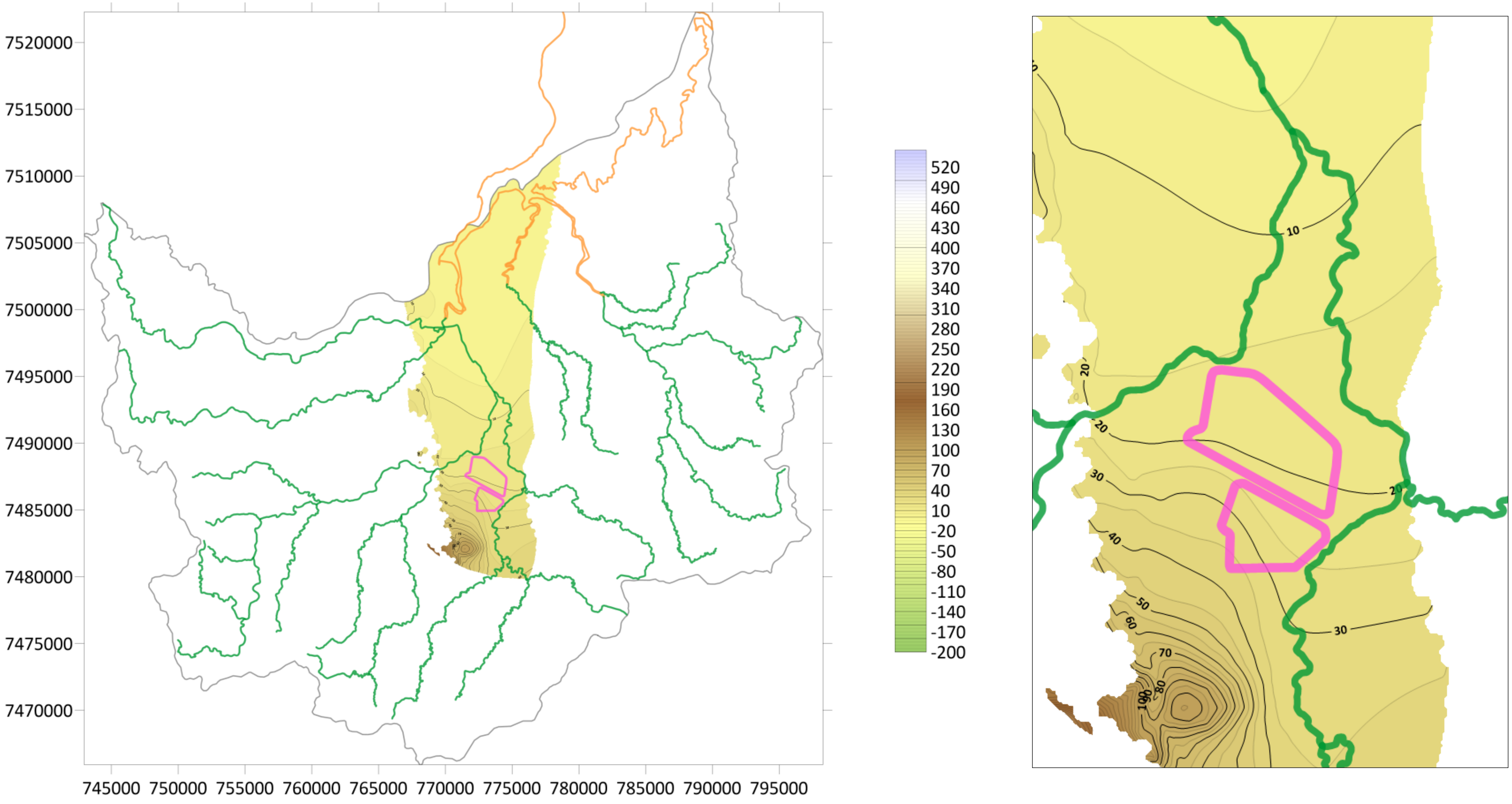
Layer 8 – Groundwater Head Plot (mAHD) – End of Calibration



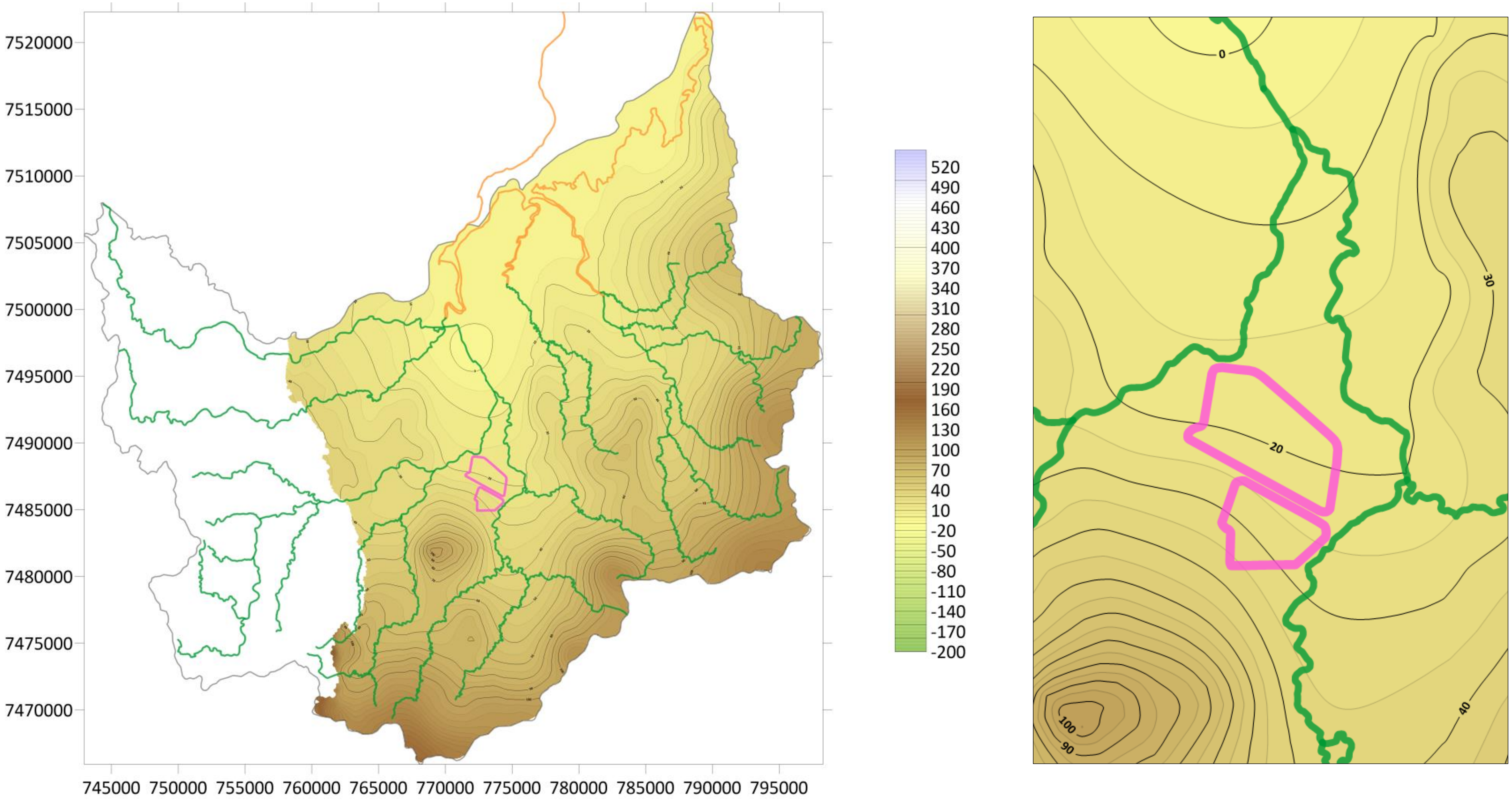
Layer 9 – Groundwater Head Plot (mAHD) – End of Calibration



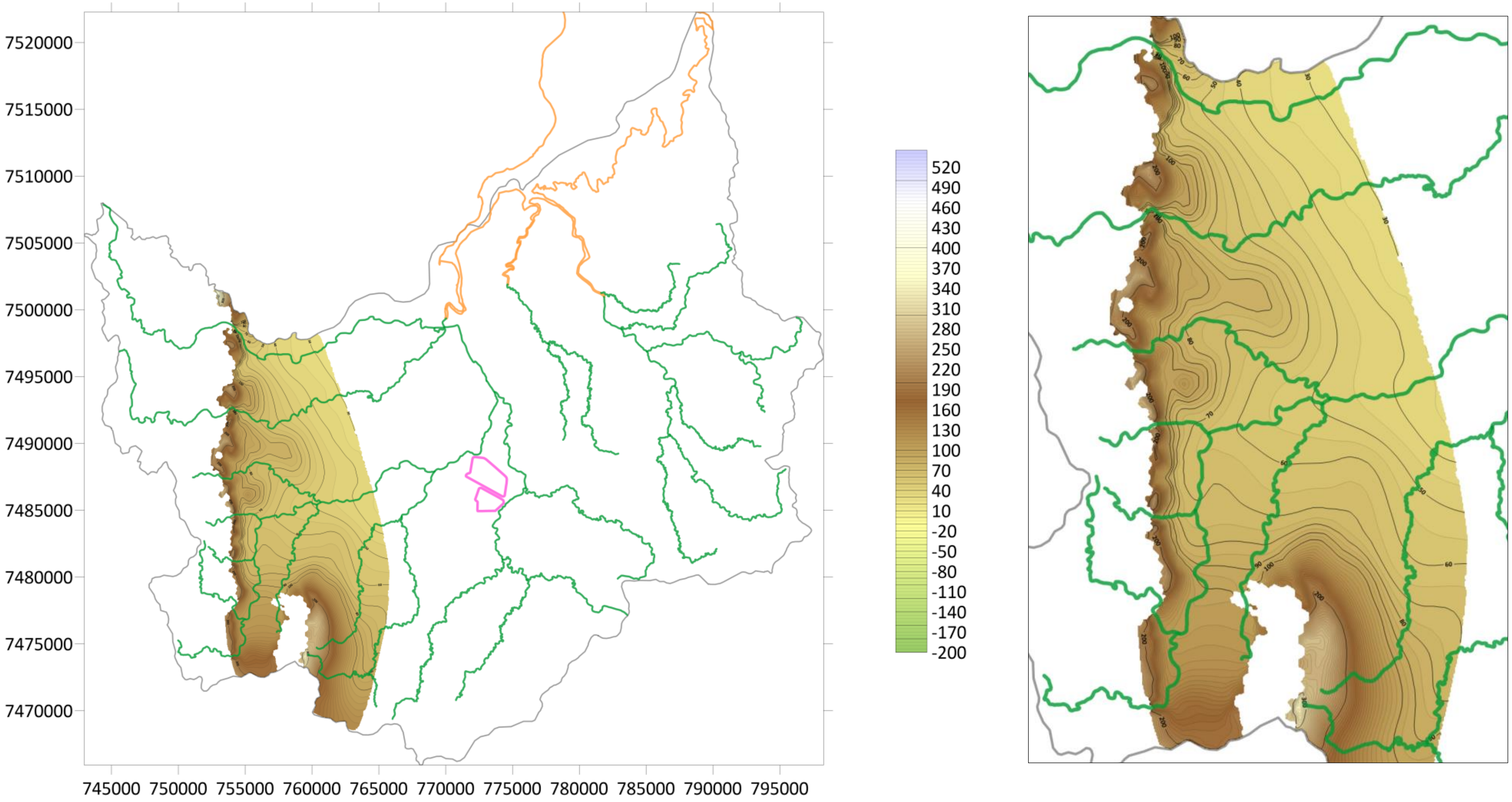
Layer 10 – Groundwater Head Plot (mAHD) – End of Calibration



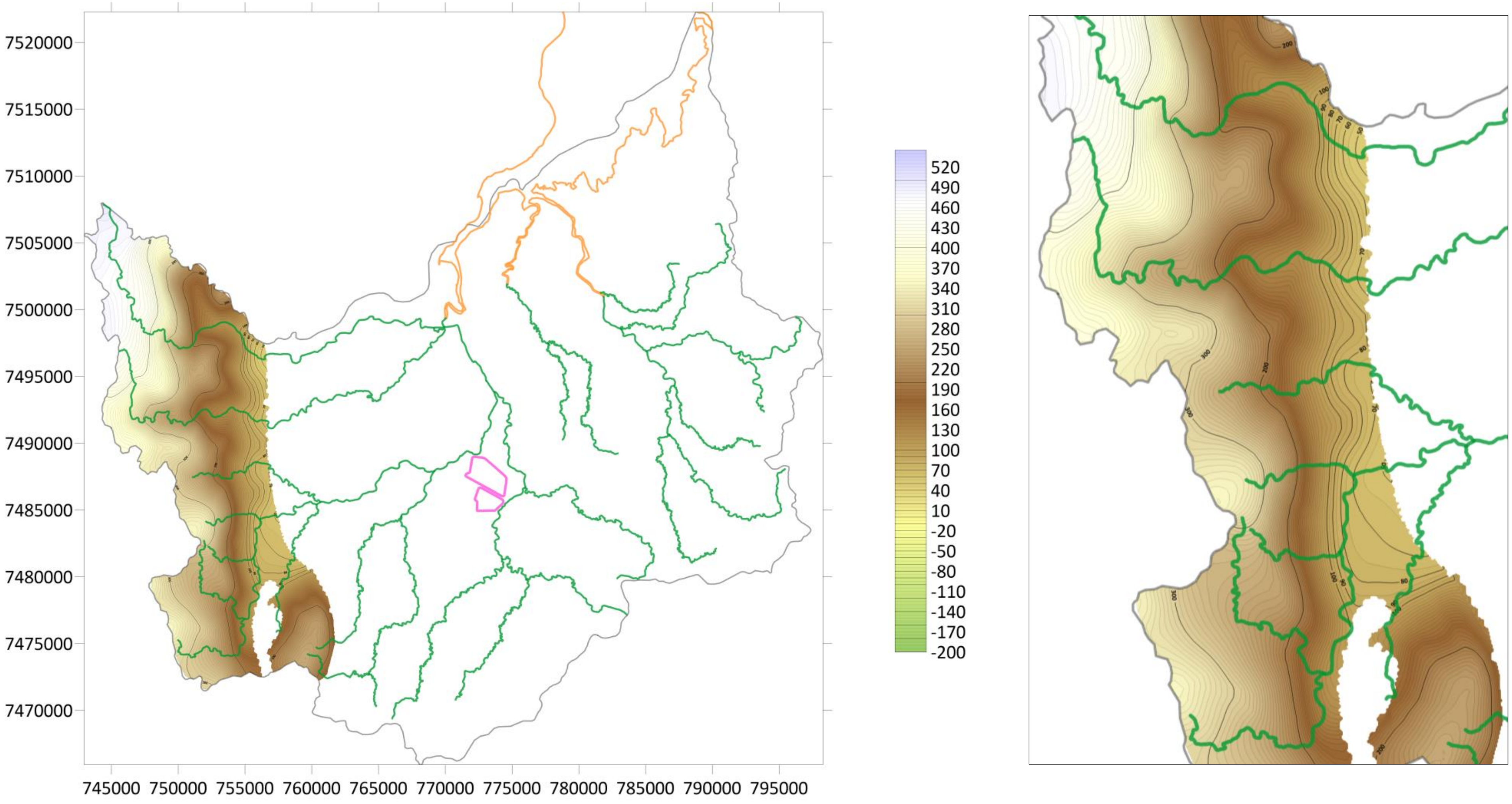
Layer 11 – Groundwater Head Plot (mAHD) – End of Calibration



Layer 12 – Groundwater Head Plot (mAHD) – End of Calibration

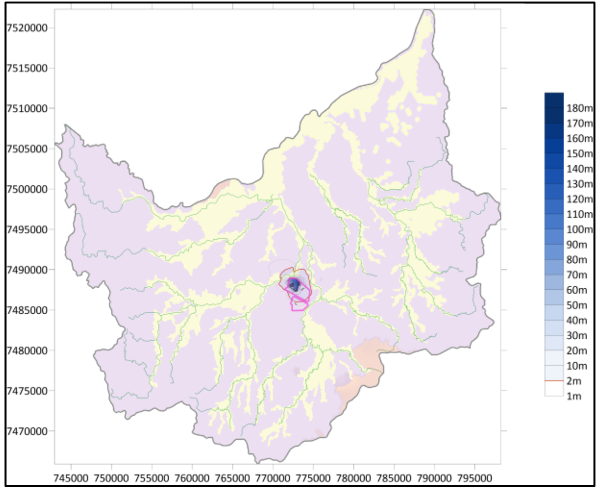


Layer 13 – Groundwater Head Plot (mAHD) – End of Calibration

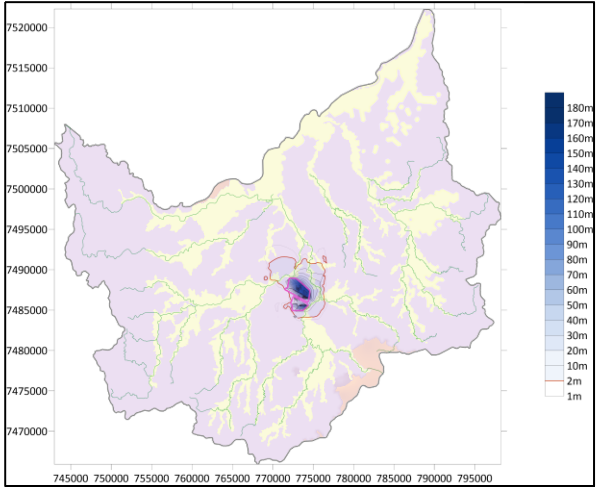


Layer 14 – Groundwater Head Plot (mAHD) – End of Calibration

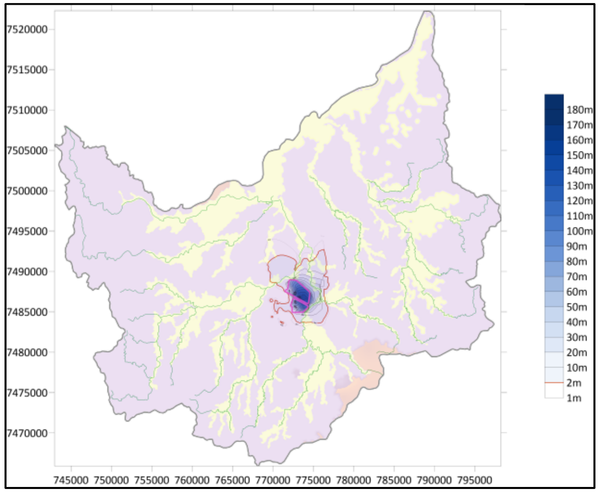
ATTACHMENT 14
MODEL LAYER SPATIAL DRAWDOWN PLOTS – DURING MINING



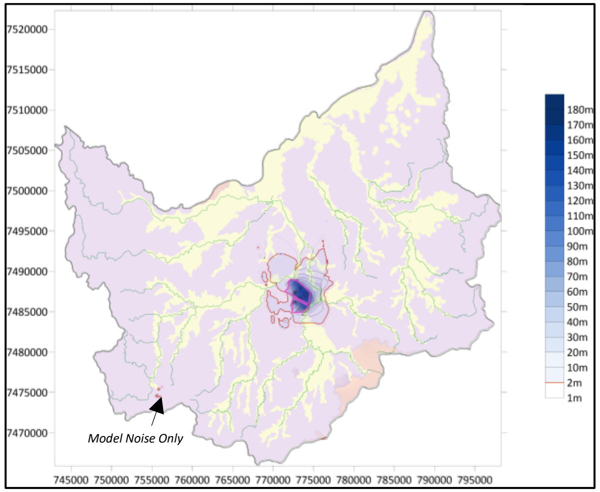
[a] After 3 Years Mining (Model Stress Period 106) [m]

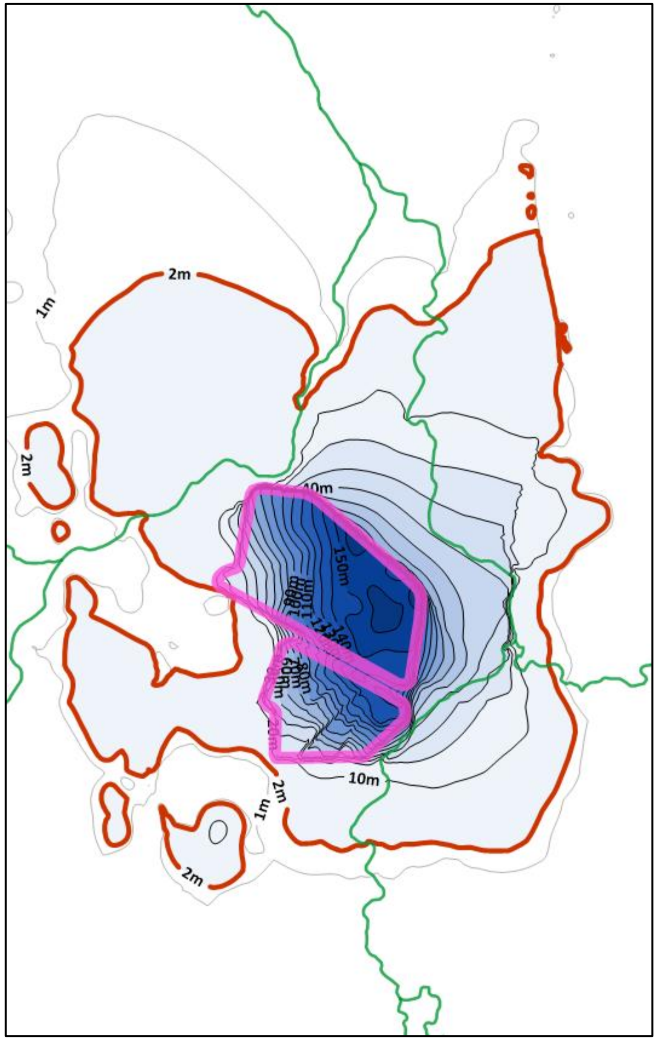


[b] After 10 Years Mining (Model Stress Period 190) [m]



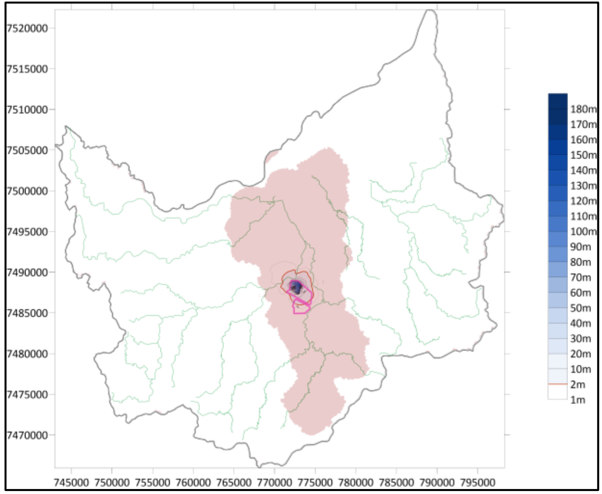
[c] End of Mining (Model Stress Period 284) [m]

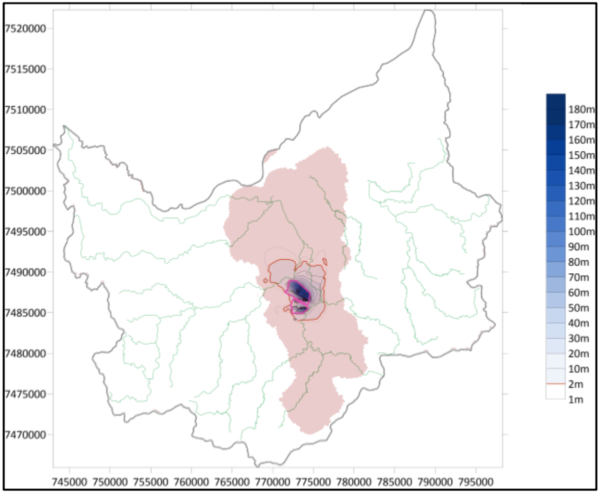




[d] Maximum Spatial Drawdown Contour Map (All Periods Combined) [m]

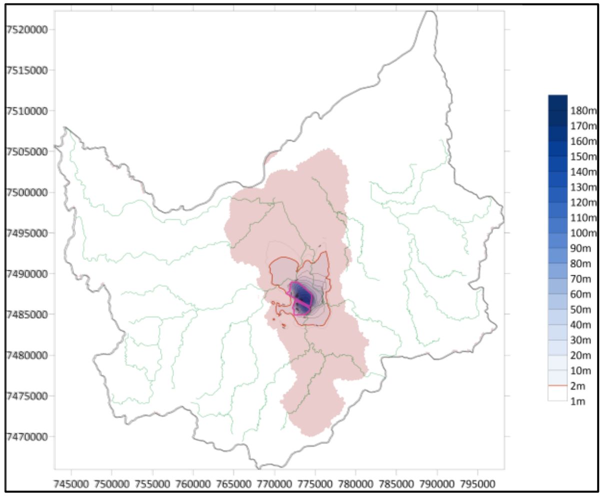
Layer 2 – Groundwater Drawdown Plots

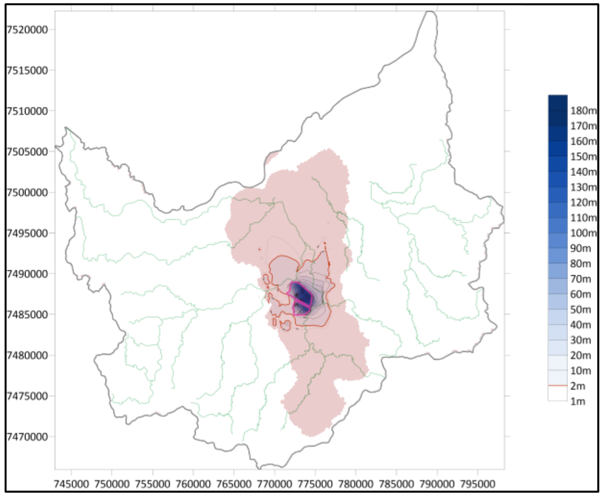


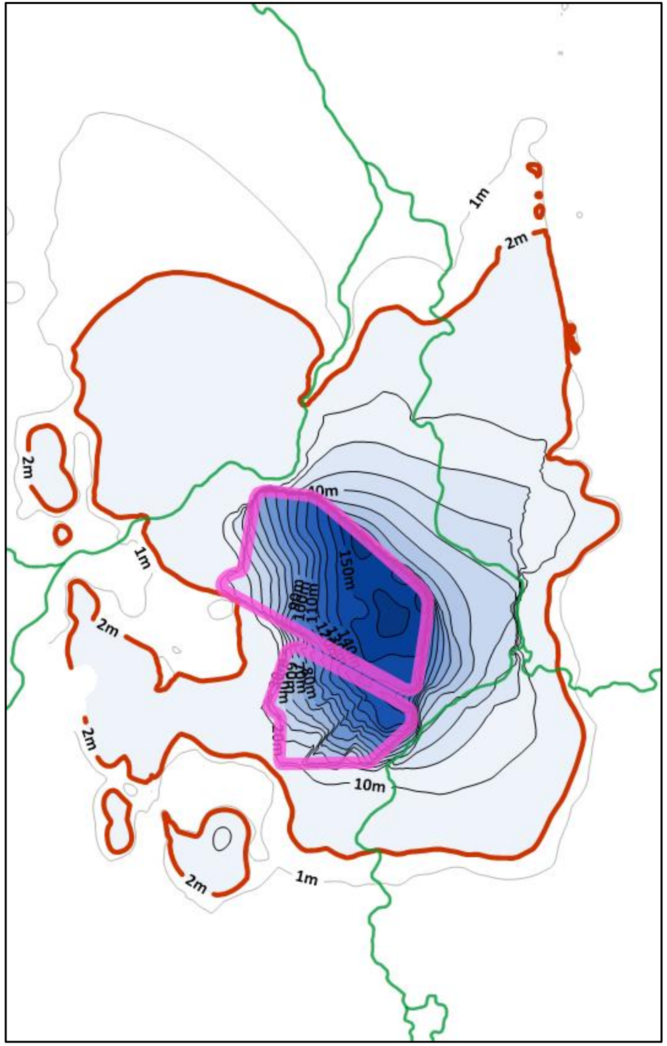


[a] After 3 Years Mining (Model Stress Period 106) [m]

[b] After 10 Years Mining (Model Stress Period 190) [m]



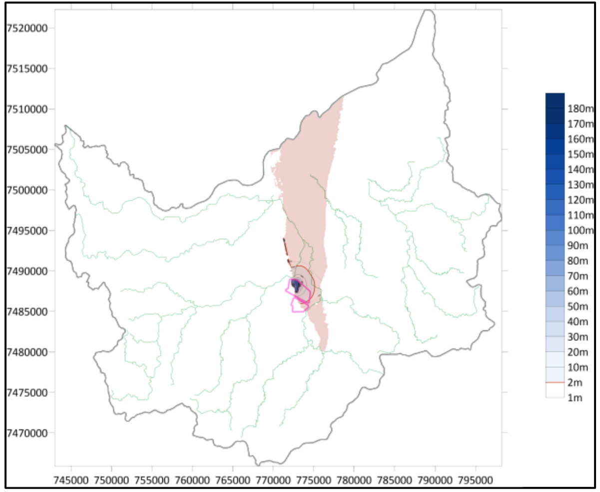


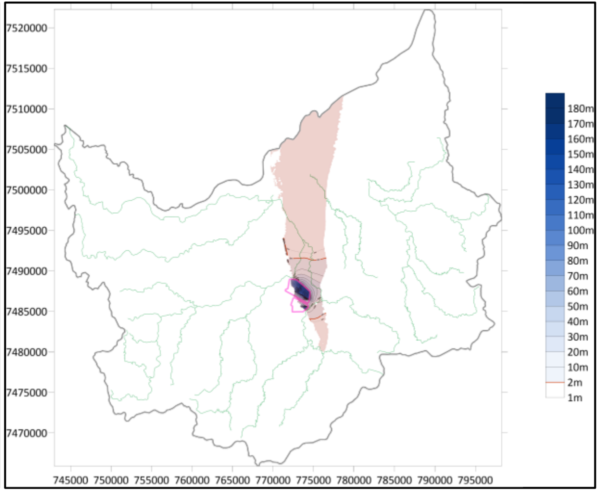


[c] End of Mining (Model Stress Period 284) [m]

[d] Maximum Spatial Drawdown Contour Map (All Periods Combined) [m]

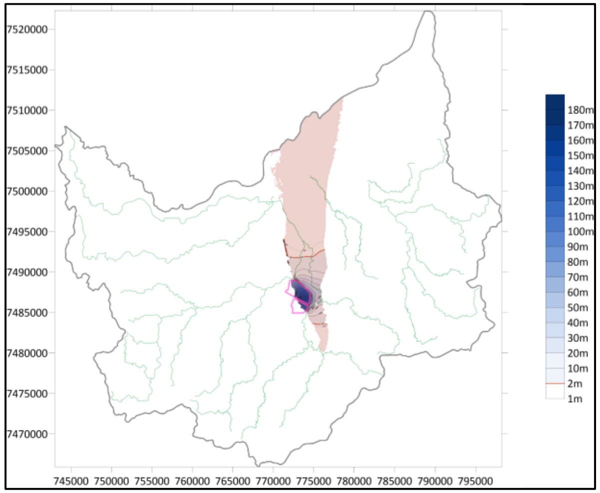
Layer 3 - Groundwater Drawdown Plots

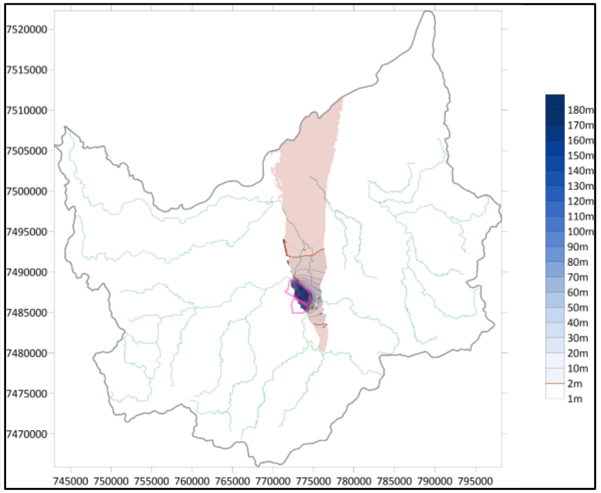


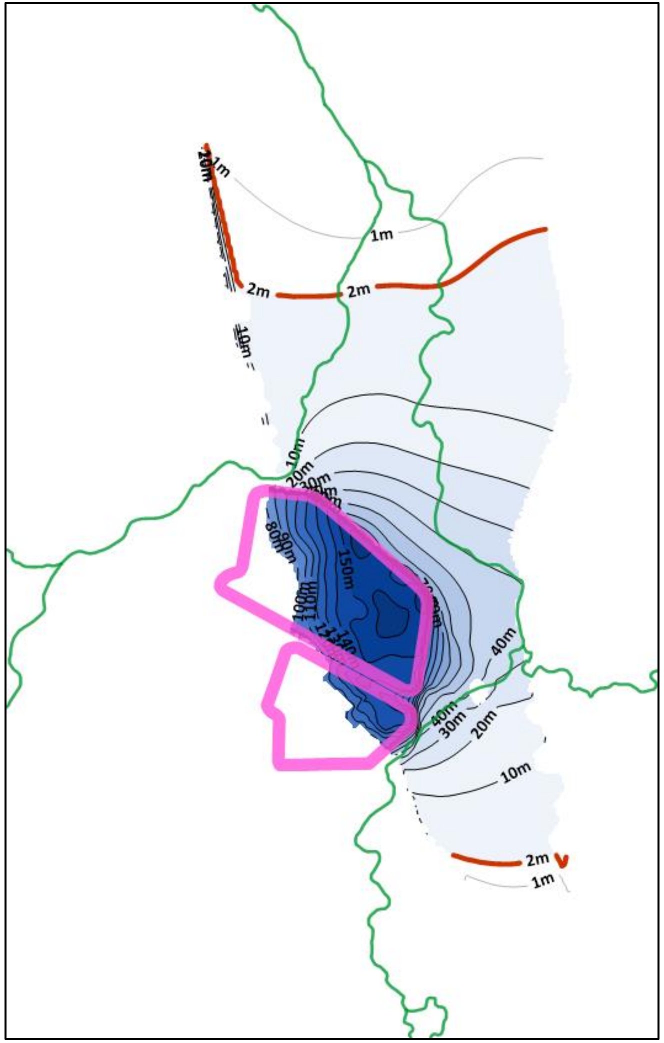


[a] After 3 Years Mining (Model Stress Period 106) [m]

[b] After 10 Years Mining (Model Stress Period 190) [m]



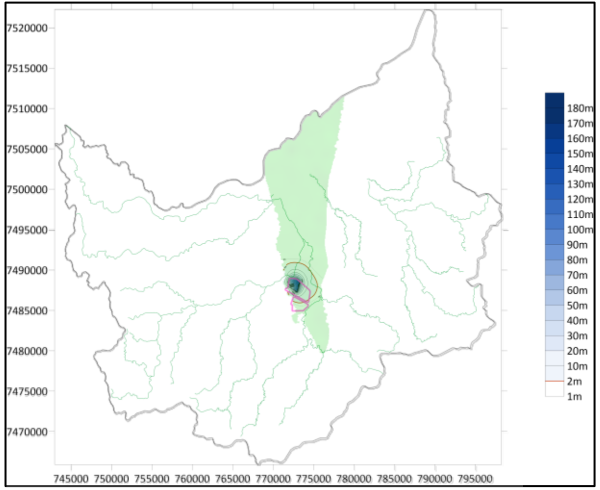




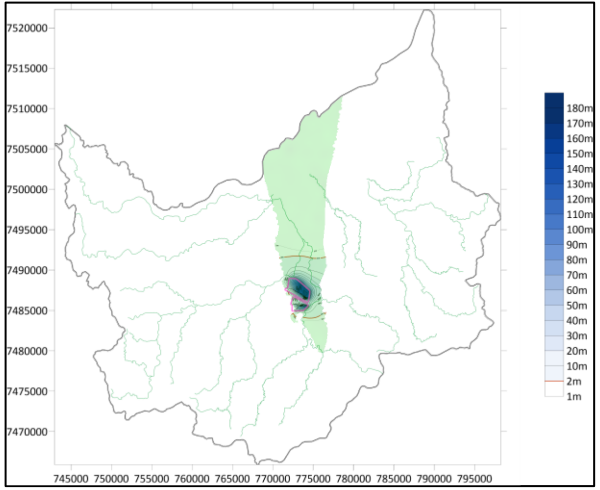
[c] End of Mining (Model Stress Period 284) [m]

[d] Maximum Spatial Drawdown Contour Map (All Periods Combined) [m]

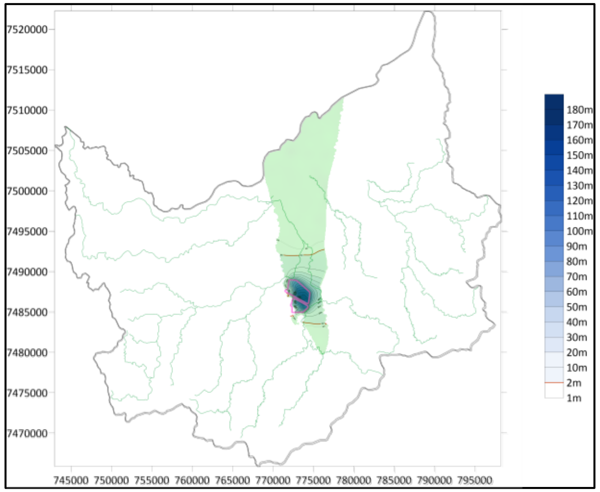
Layer 5 - Groundwater Drawdown Plots



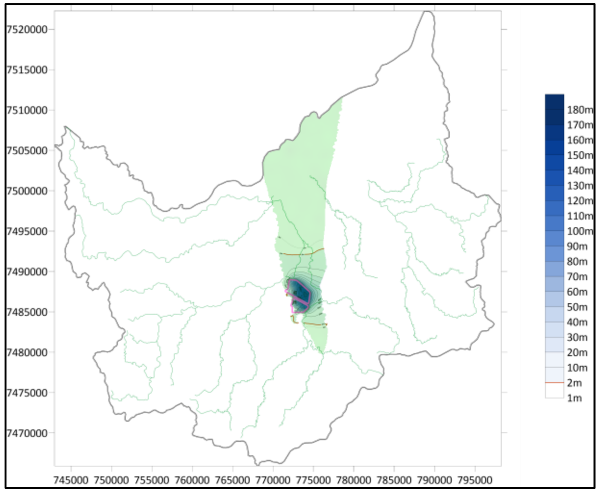
[a] After 3 Years Mining (Model Stress Period 106) [m]

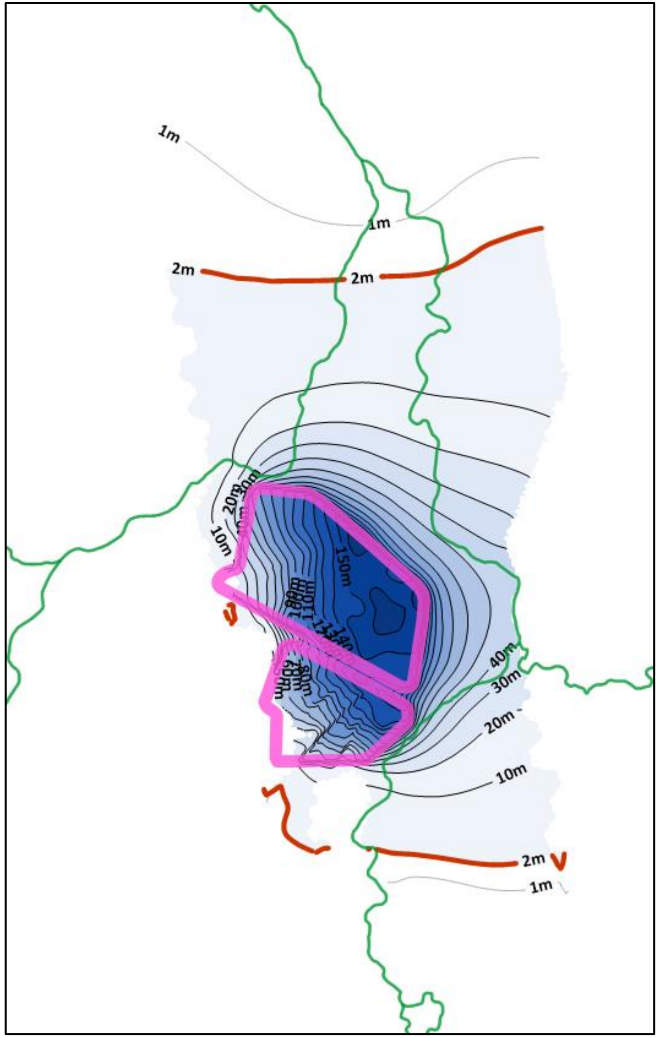


[b] After 10 Years Mining (Model Stress Period 190) [m]



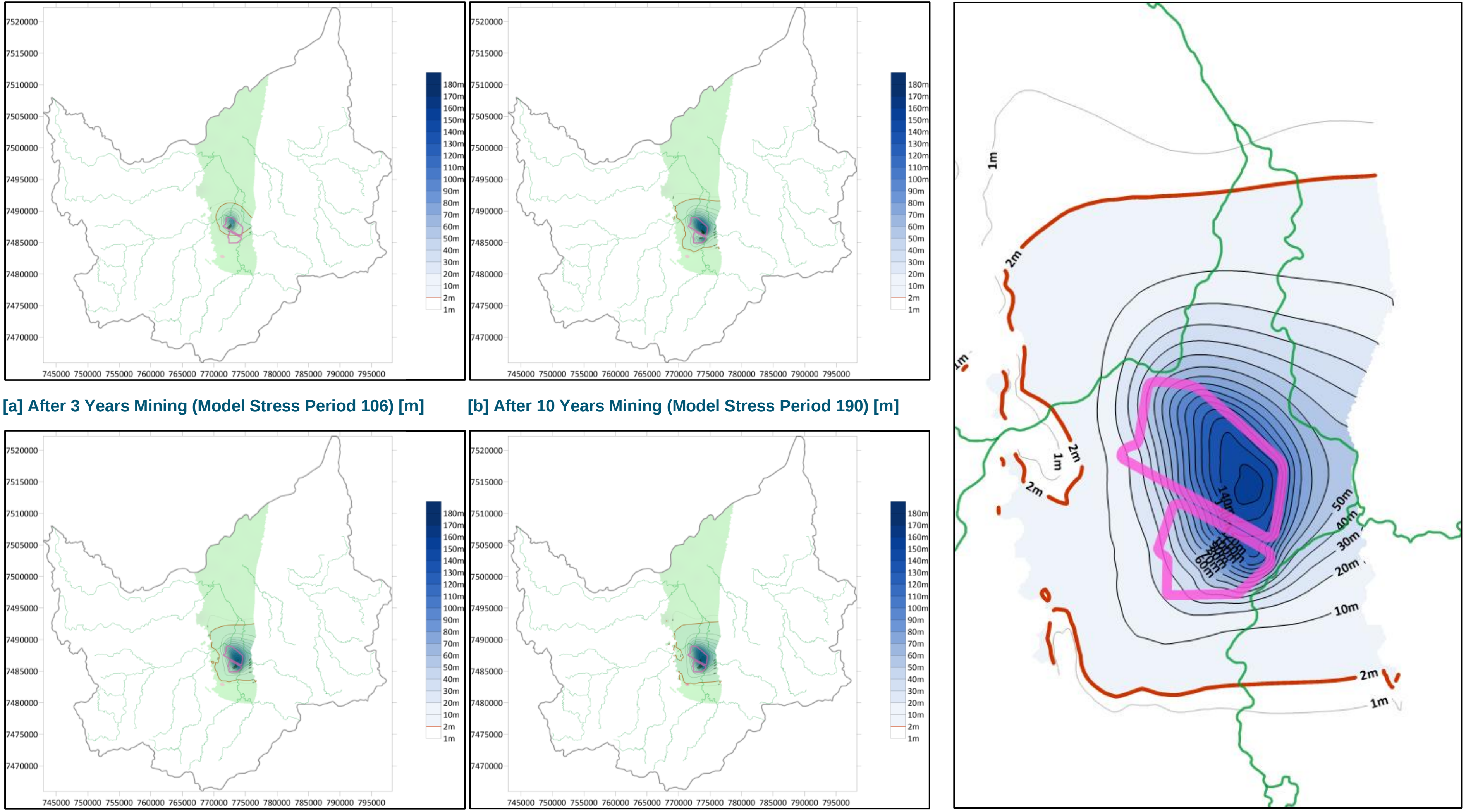
[c] End of Mining (Model Stress Period 284) [m]





[d] Maximum Spatial Drawdown Contour Map (All Periods Combined) [m]

Layer 8 - Groundwater Drawdown Plots



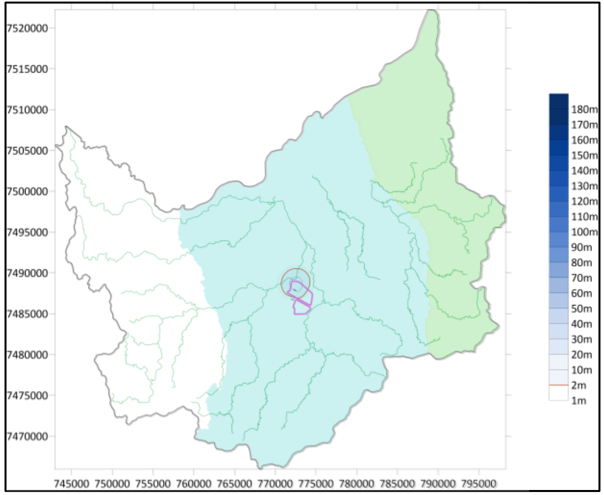
[a] After 3 Years Mining (Model Stress Period 106) [m]

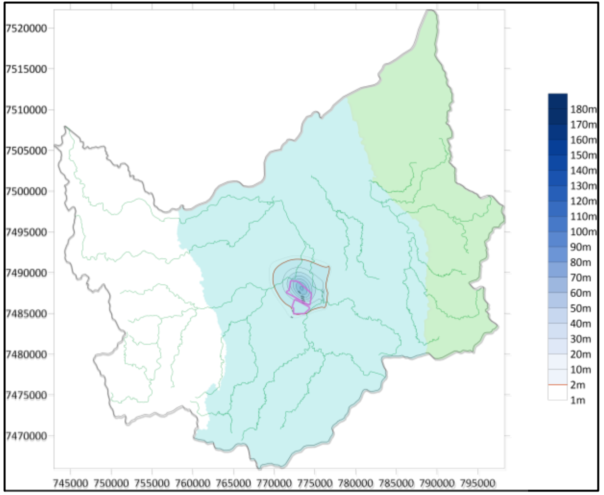
[b] After 10 Years Mining (Model Stress Period 190) [m]

[c] End of Mining (Model Stress Period 284) [m]

[d] Maximum Spatial Drawdown Contour Map (All Periods Combined) [m]

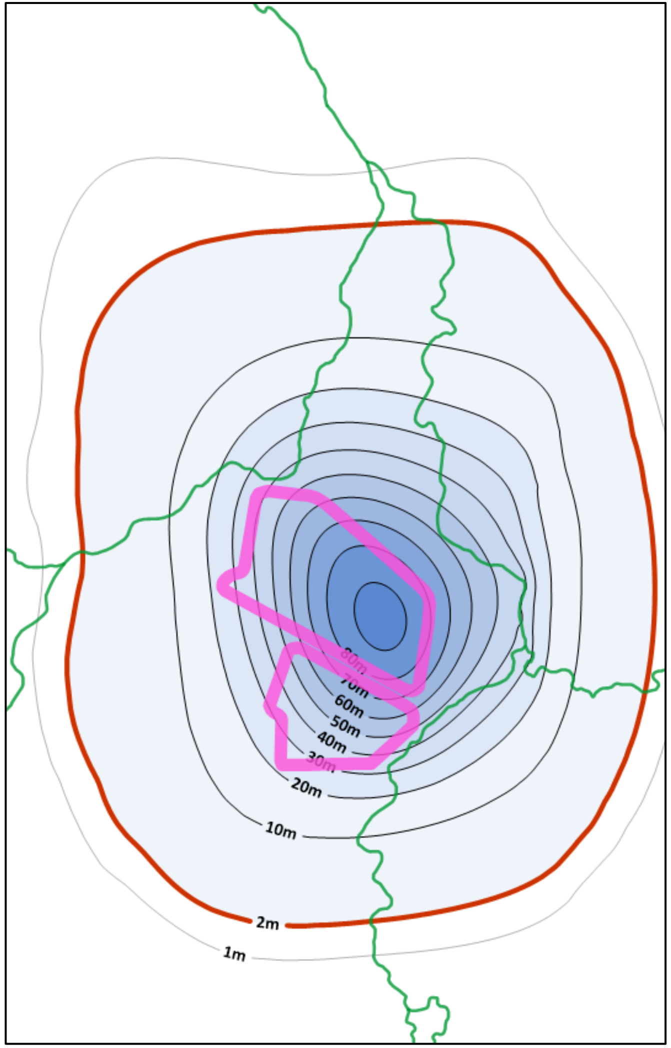
Layer 11 - Groundwater Drawdown Plots

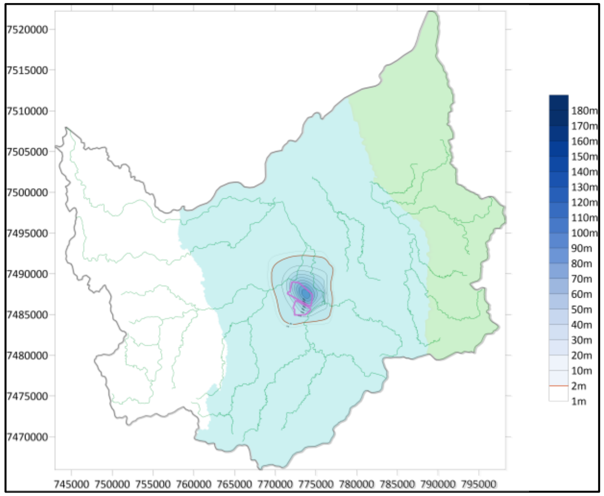


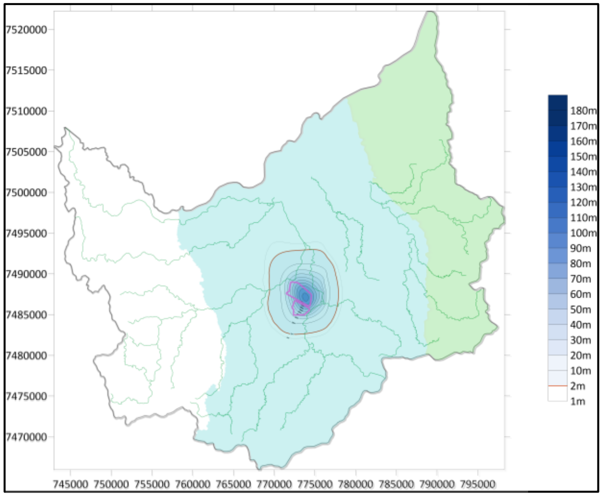


[a] After 3 Years Mining (Model Stress Period 106) [m]

[b] After 10 Years Mining (Model Stress Period 190) [m]





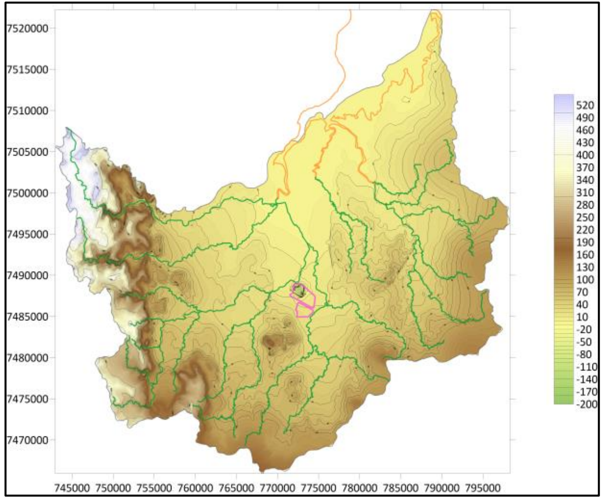


[c] End of Mining (Model Stress Period 284) [m]

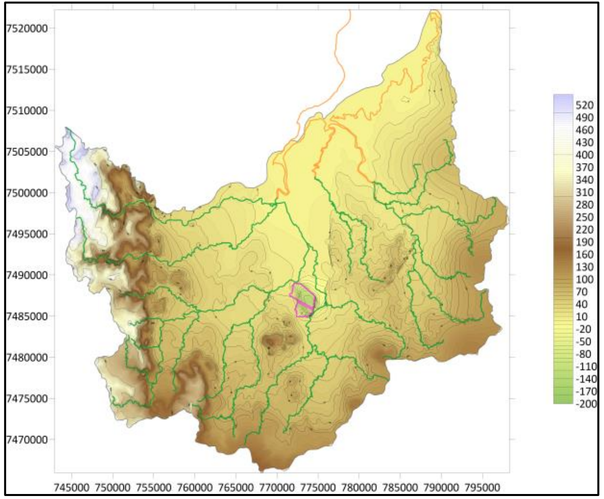
[d] Maximum Spatial Drawdown Contour Map (All Periods Combined) [m]

Layer 12 - Groundwater Drawdown Plots

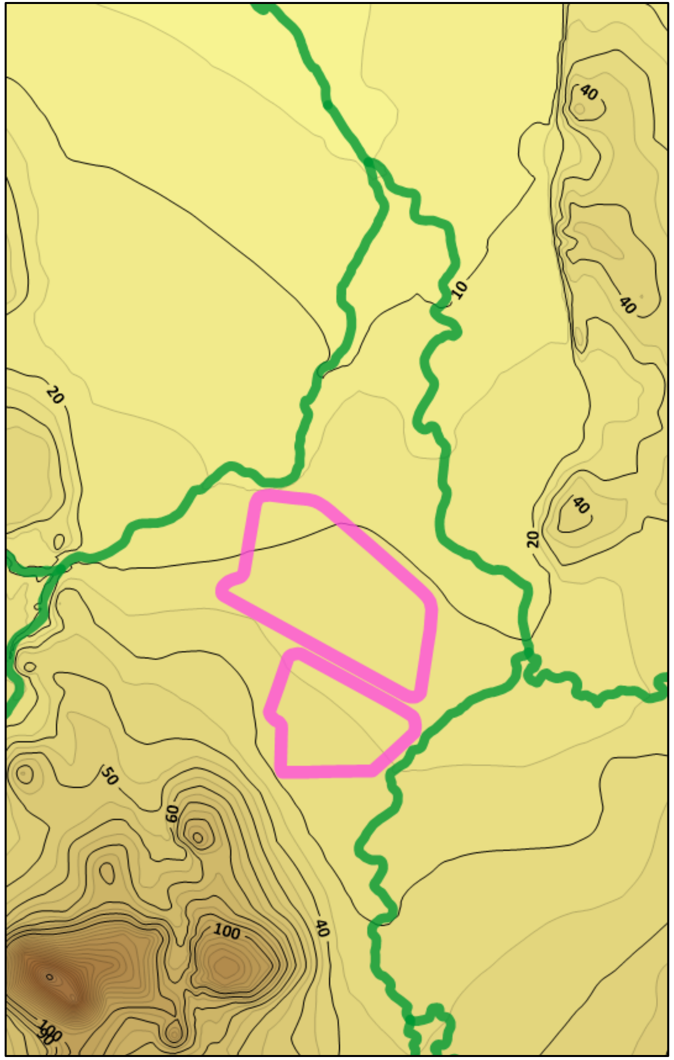
ATTACHMENT 15
MODEL LAYER HEAD PLOTS – DURING AND POST-MINING

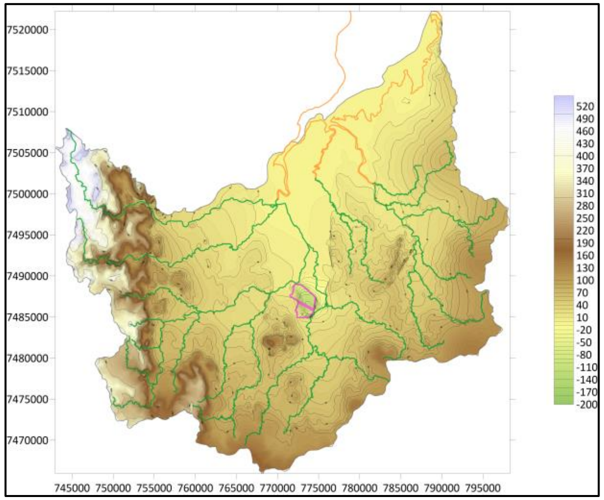


[a] After 3 Years Mining (Model Stress Period 106)

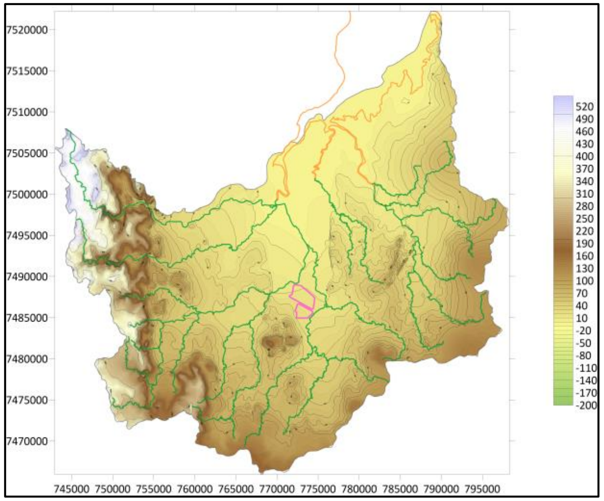


[b] End of Mining (Model Stress Period 284)



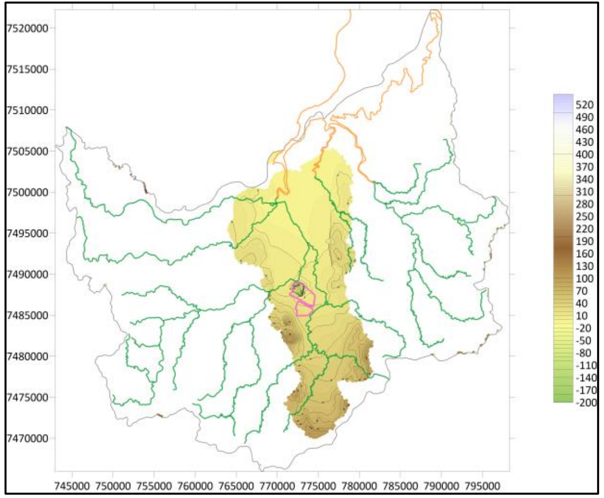


[c] After 5 Years Post-Mining (Model Stress Period 300)

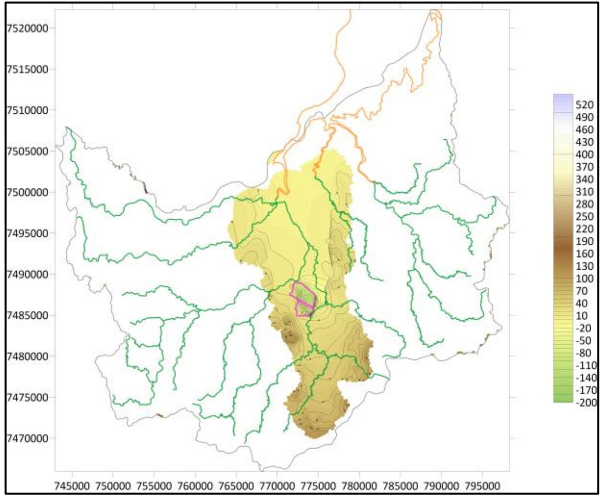


[d] Long-Term Recovery (Model Stress Period 320)

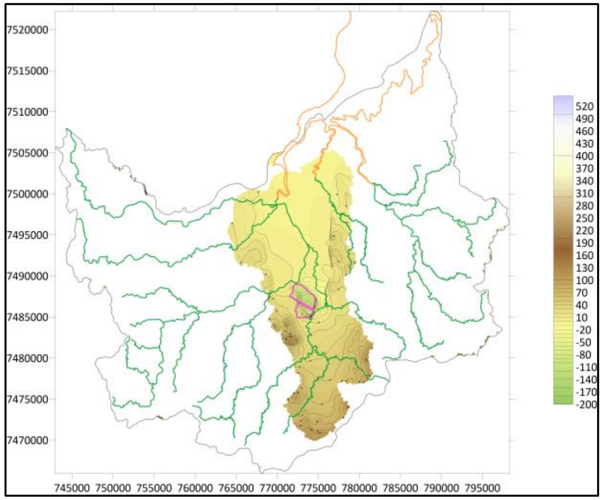
Layer 2 – Groundwater Head Plot (mAHD)



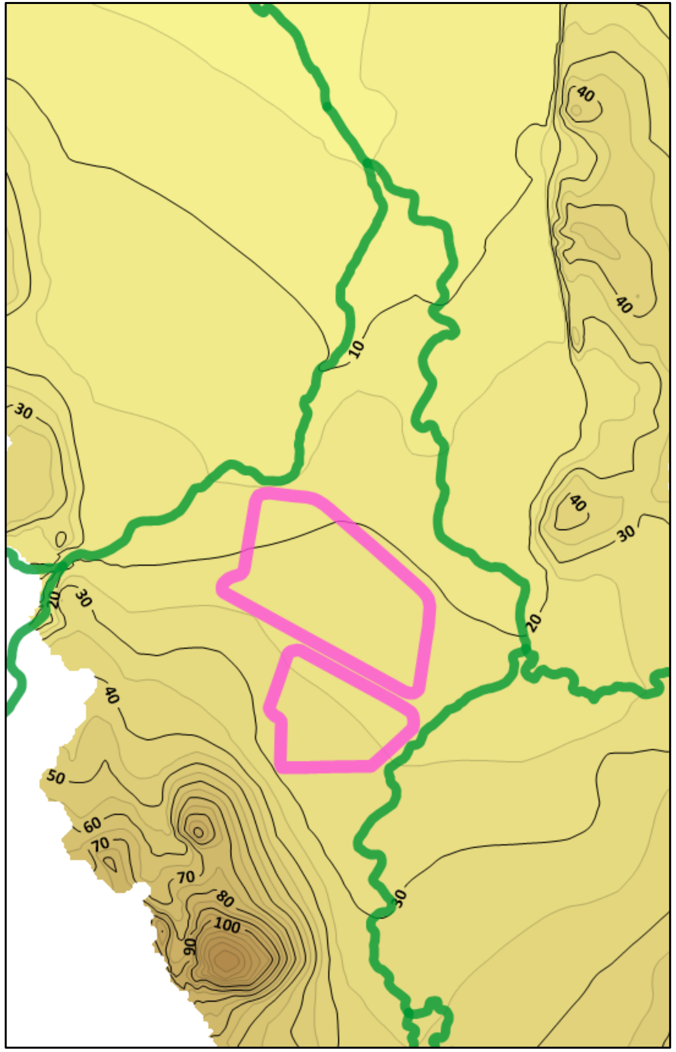
[a] After 3 Years Mining (Model Stress Period 106)



[b] End of Mining (Model Stress Period 284)

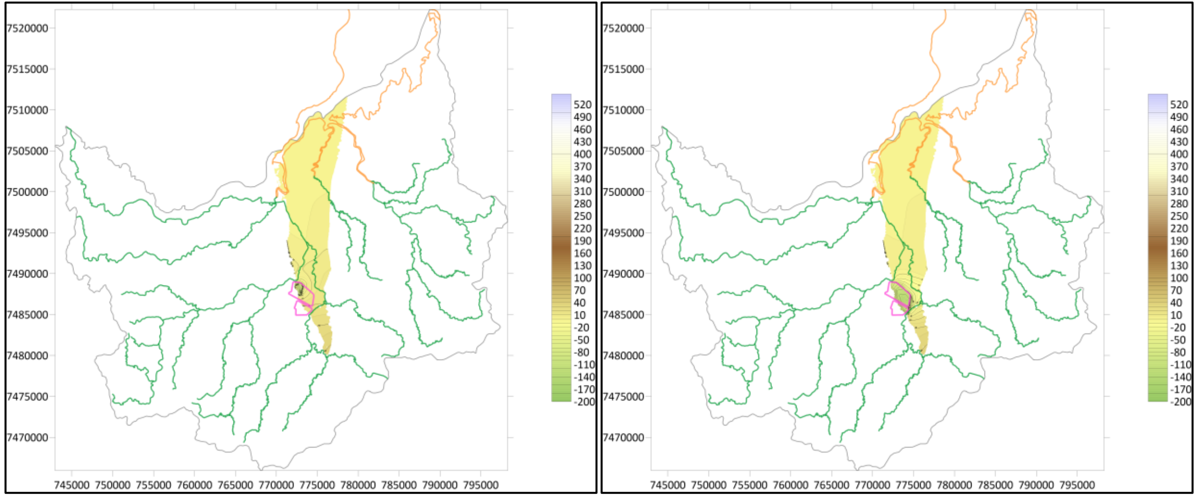


[c] After 5 Years Post-Mining (Model Stress Period 300)



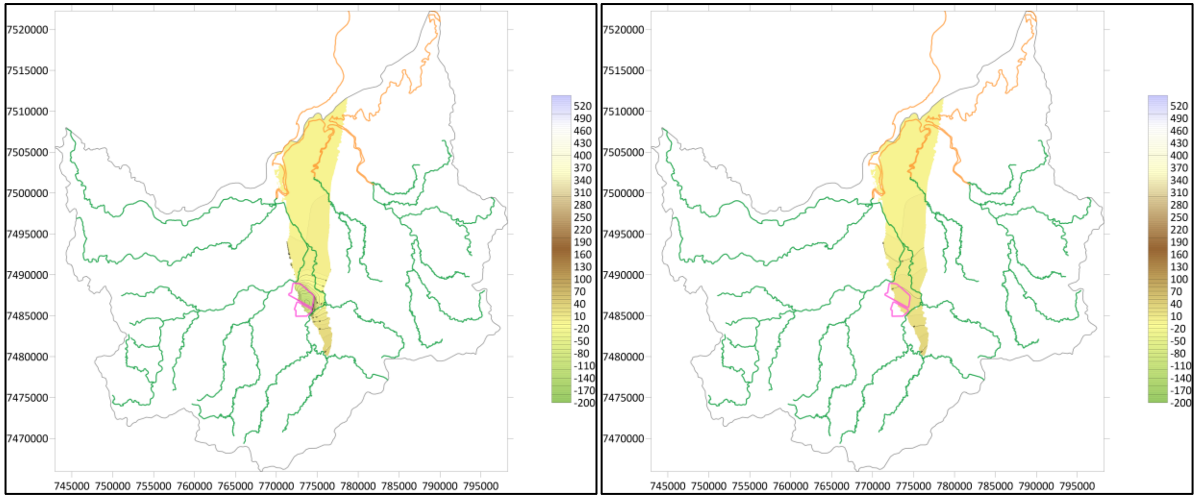
[d] Long-Term Recovery (Model Stress Period 320)

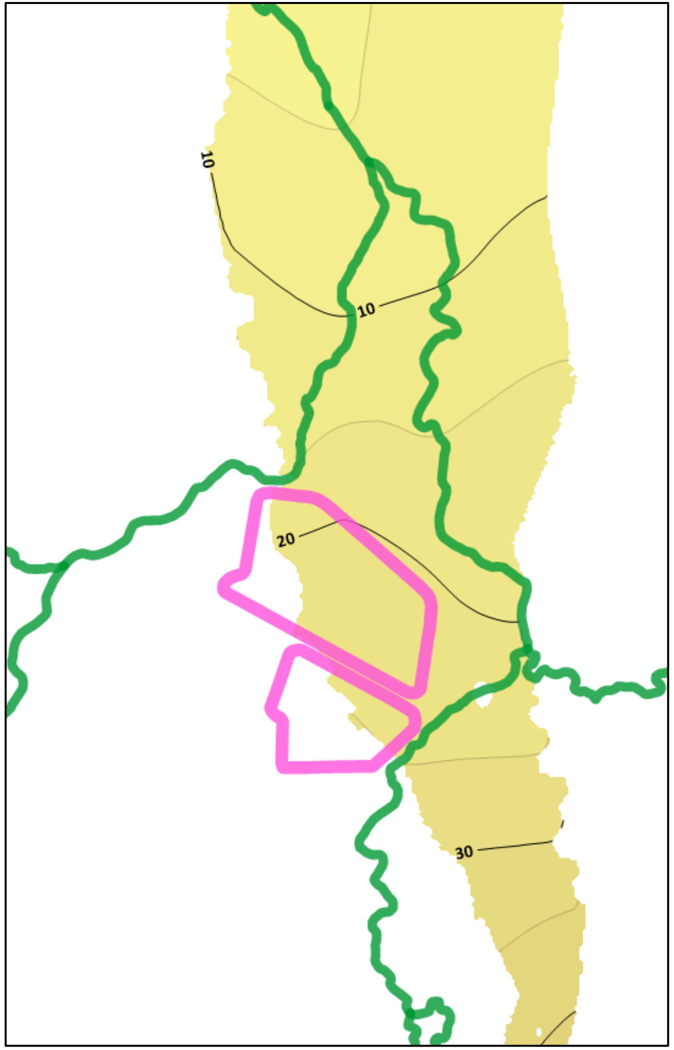
Layer 3 – Groundwater Head Plot (mAHD)



[a] After 3 Years Mining (Model Stress Period 106)

[b] End of Mining (Model Stress Period 284)

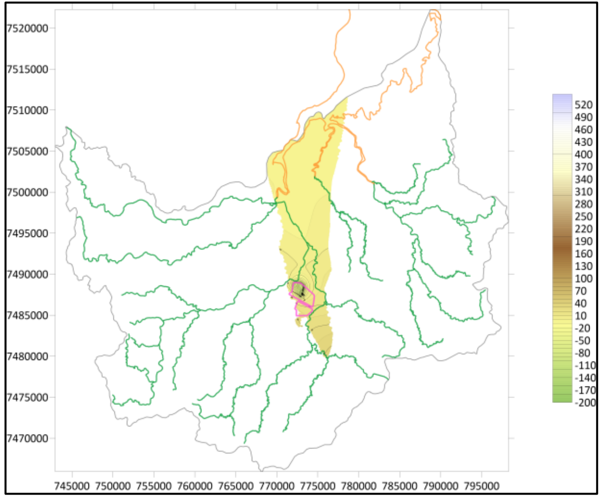


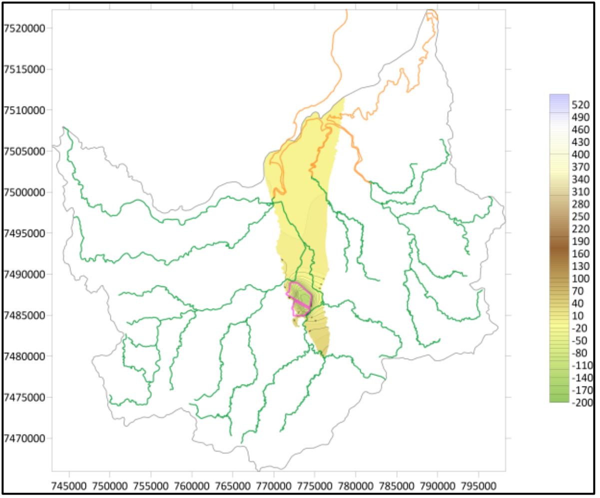


[c] After 5 Years Post-Mining (Model Stress Period 300)

[d] Long-Term Recovery (Model Stress Period 320)

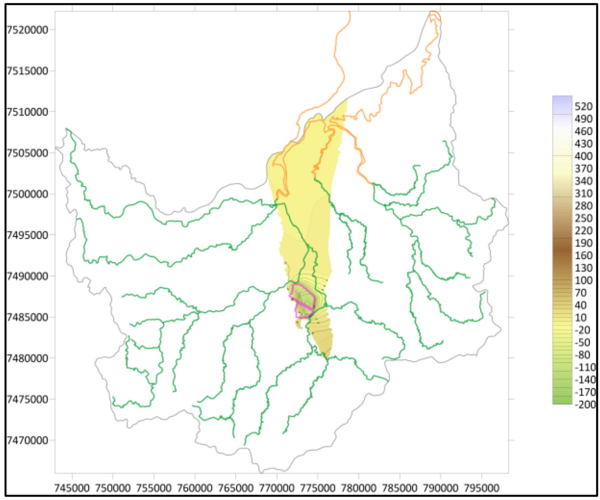
Layer 5 – Groundwater Head Plot (mAHD)

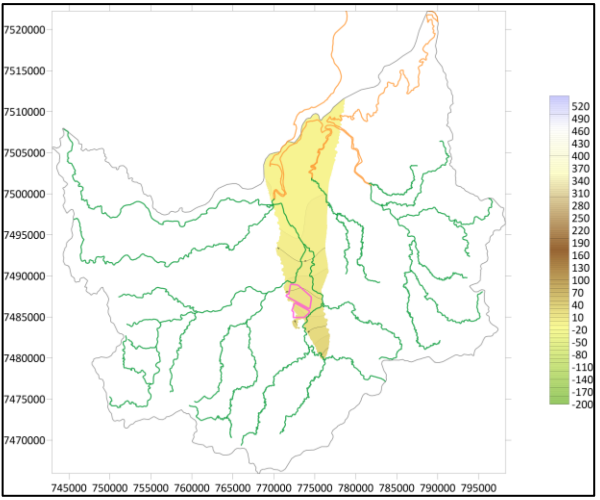


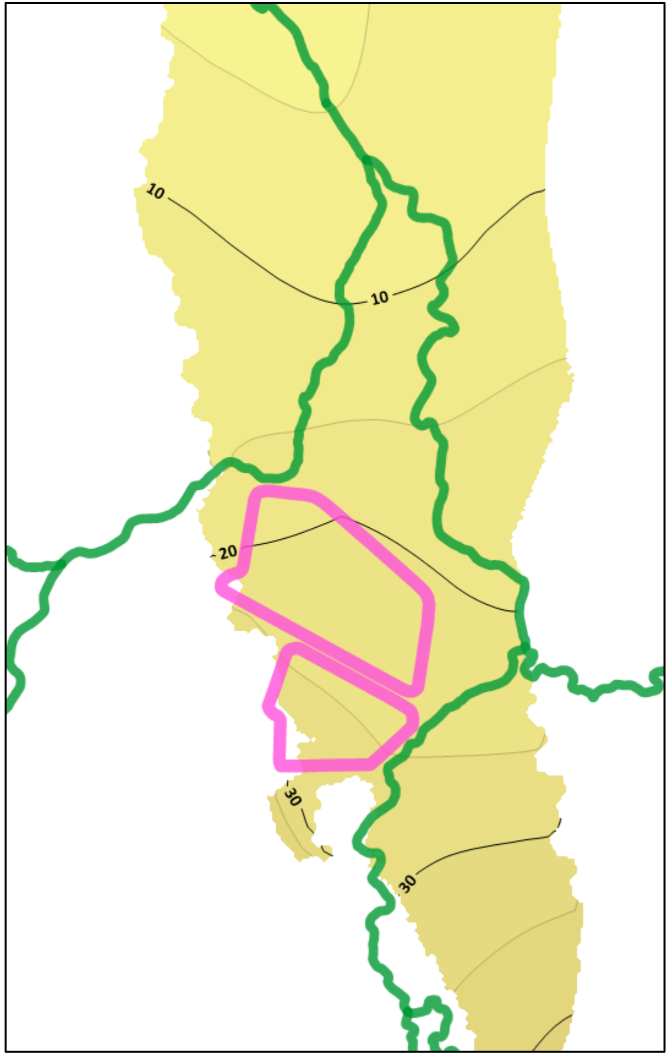


[a] After 3 Years Mining (Model Stress Period 106)

[b] End of Mining (Model Stress Period 284)



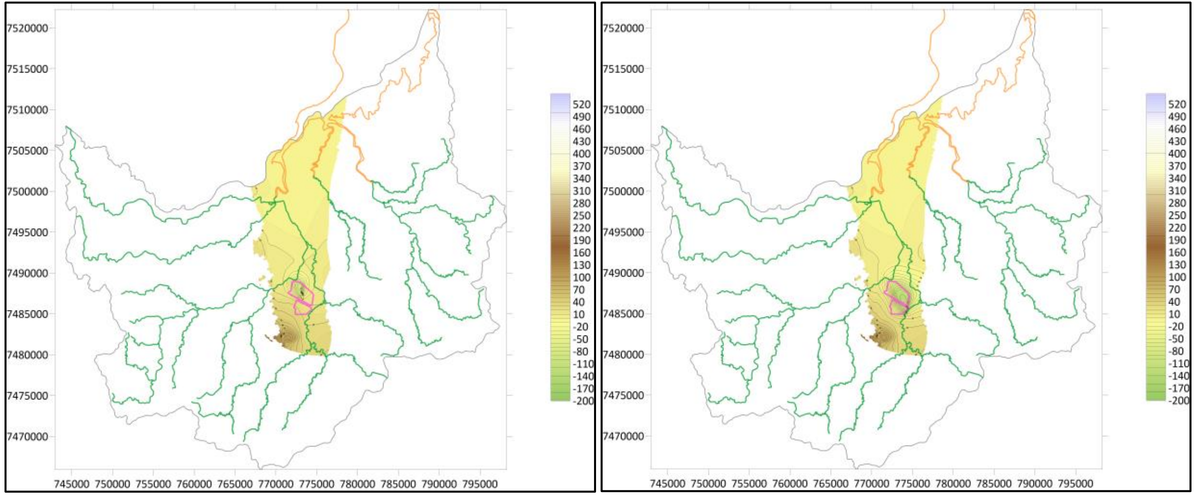




[c] After 5 Years Post-Mining (Model Stress Period 300)

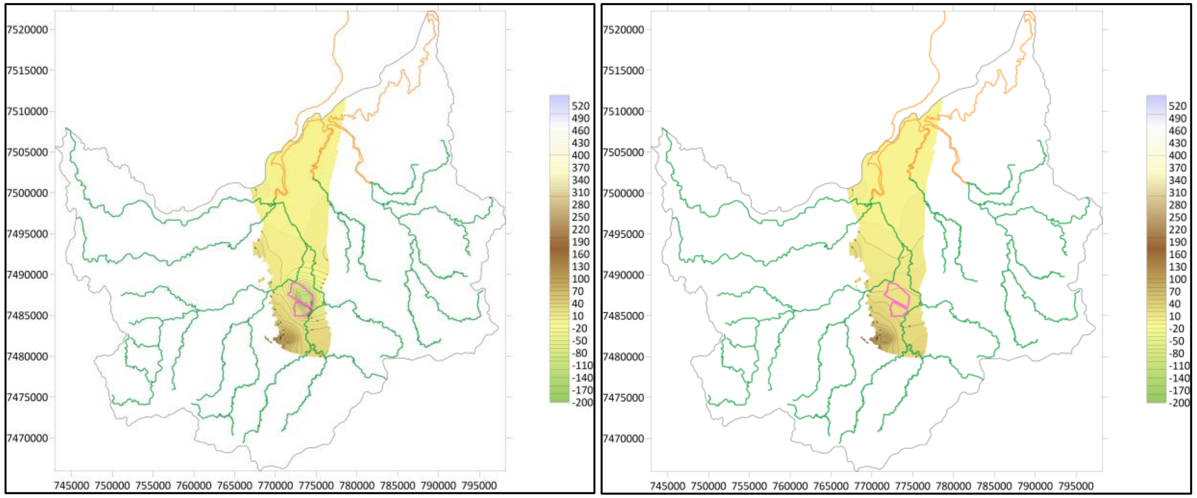
[d] Long-Term Recovery (Model Stress Period 320)

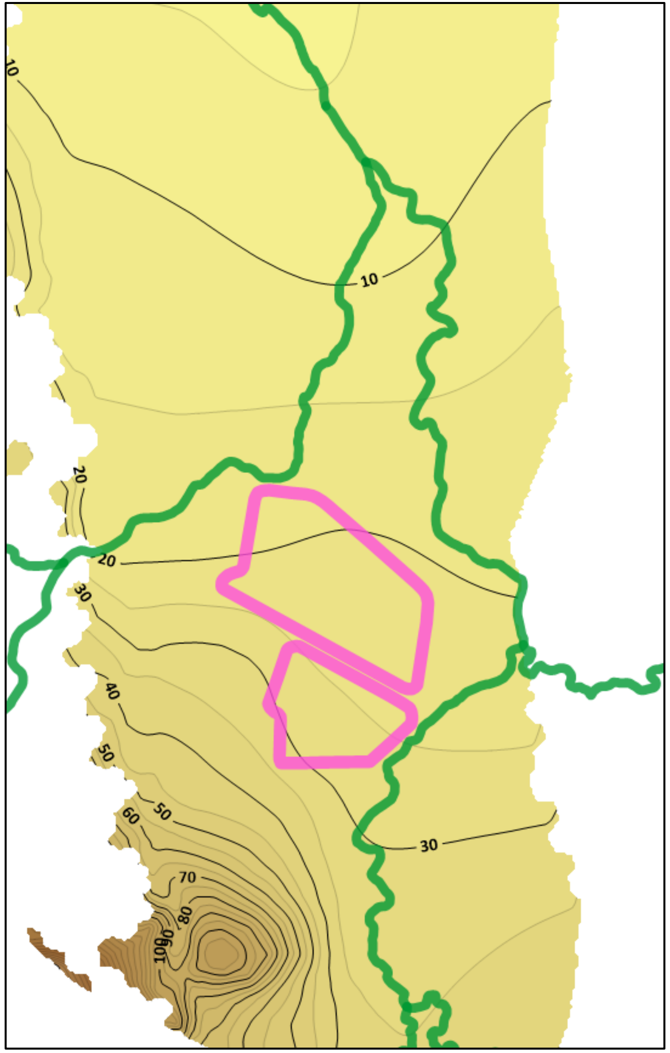
Layer 8 – Groundwater Head Plot (mAHD)



[a] After 3 Years Mining (Model Stress Period 106)

[b] End of Mining (Model Stress Period 284)

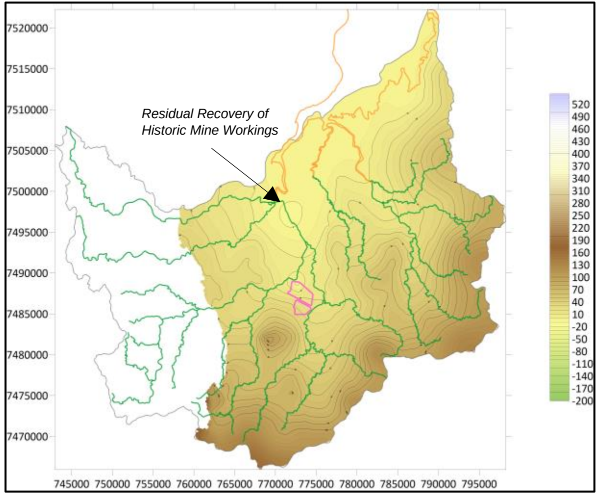




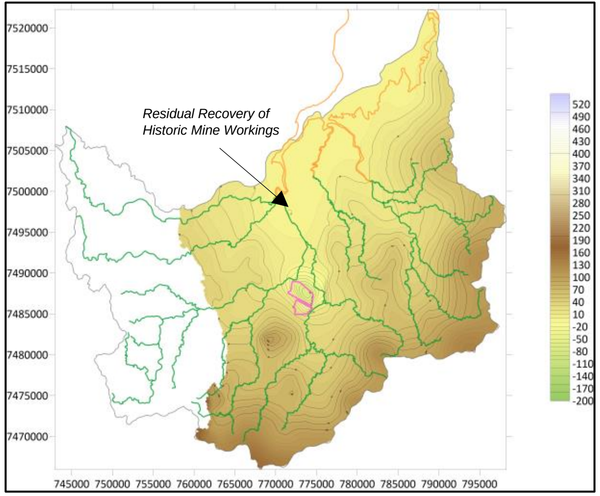
[c] After 5 Years Post-Mining (Model Stress Period 300)

[d] Long-Term Recovery (Model Stress Period 320)

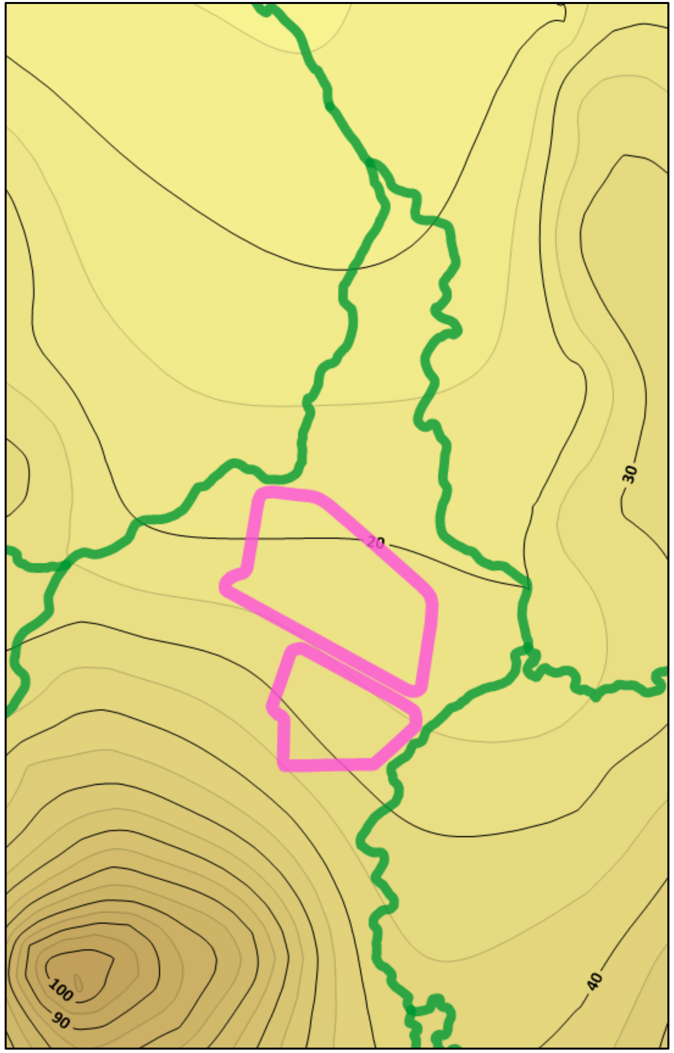
Layer 11 – Groundwater Head Plot (mAHD)

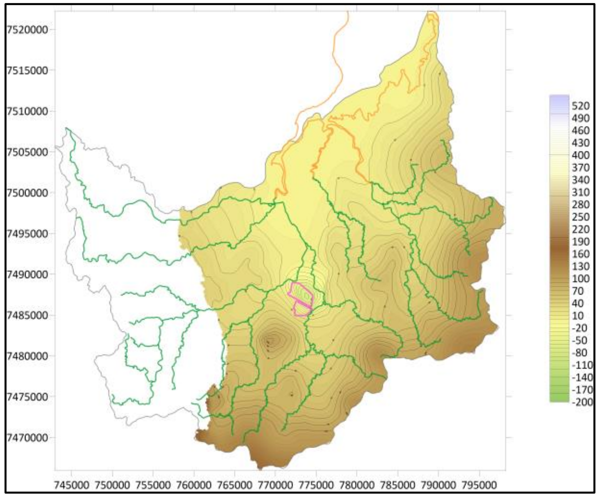


[a] After 3 Years Mining (Model Stress Period 106)

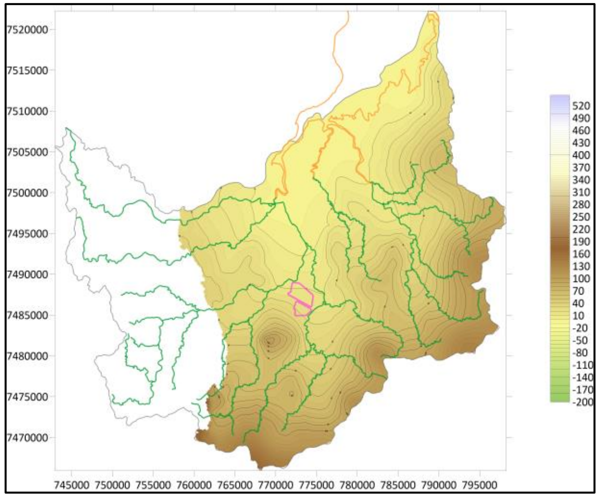


[b] End of Mining (Model Stress Period 284)





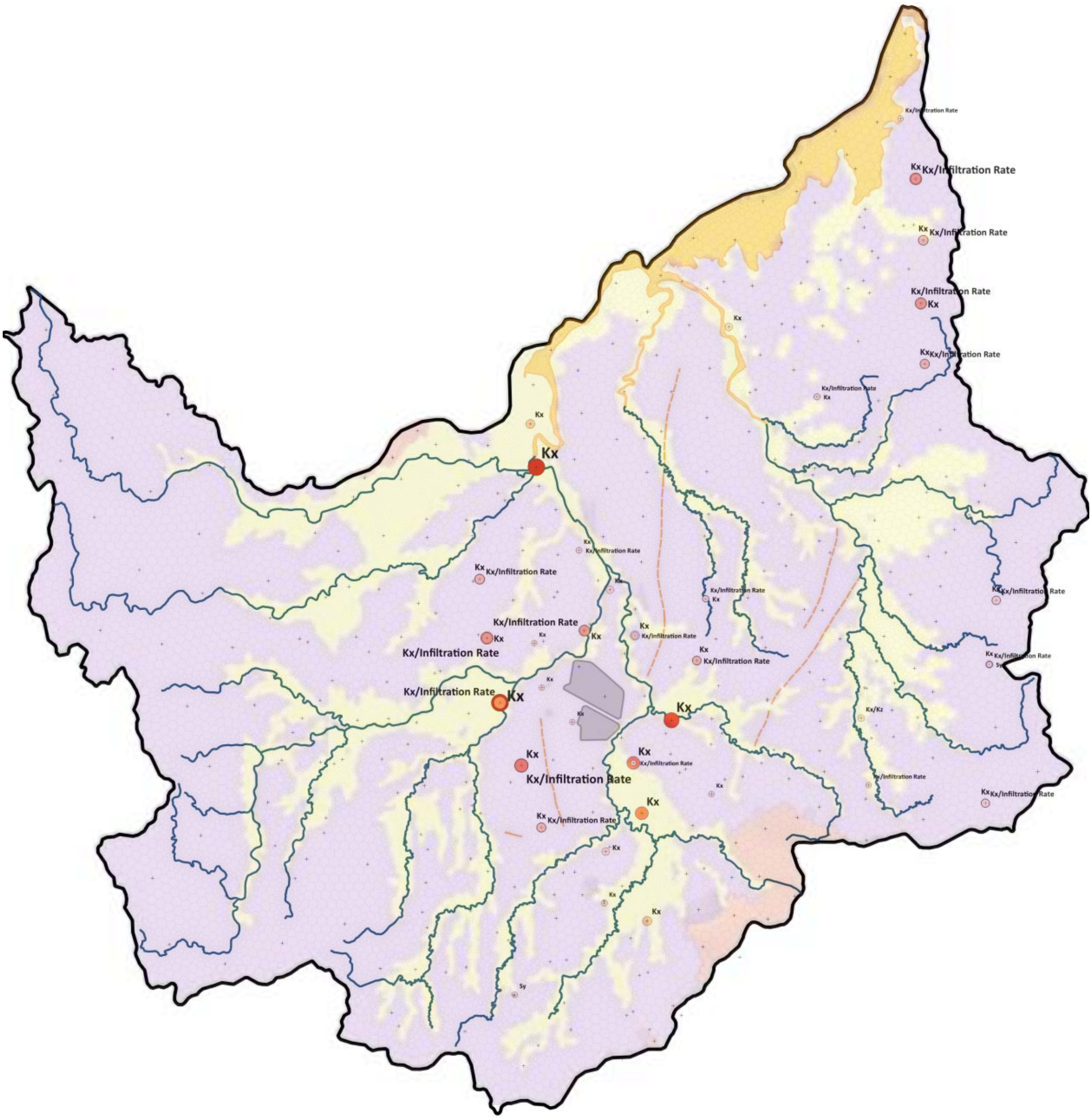
[c] After 5 Years Post-Mining (Model Stress Period 300)



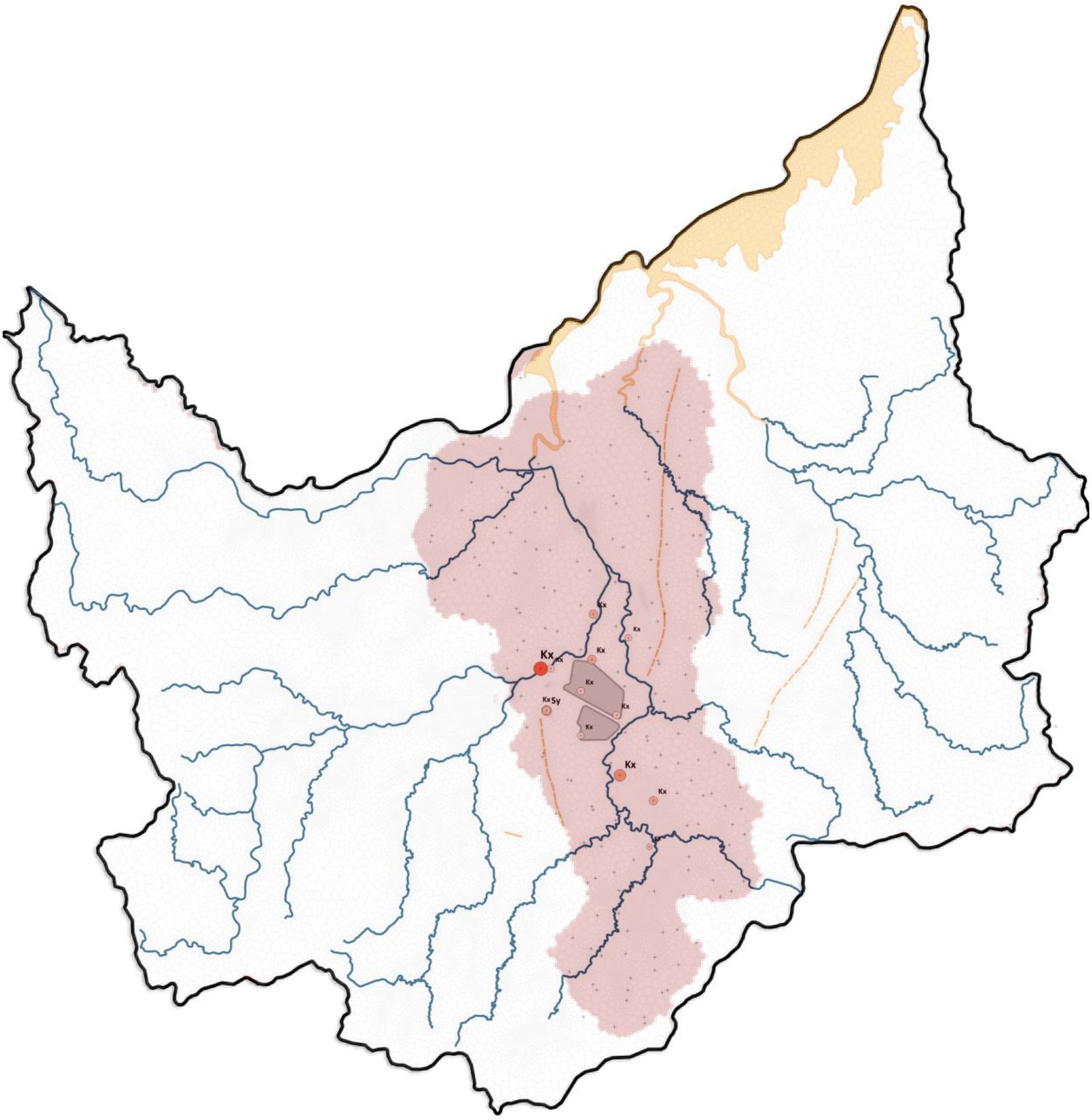
[d] Long-Term Recovery (Model Stress Period 320)

Layer 12 – Groundwater Head Plot (mAHD)

ATTACHMENT 16
PARAMETER IDENTIFIABILITY SPATIAL PLOTS



Layer 2 Parameter Identifiability
['+' = <0.1; >0.1 – 1.0 with red circles increasing in relative size]



Layer 3 Parameter Identifiability
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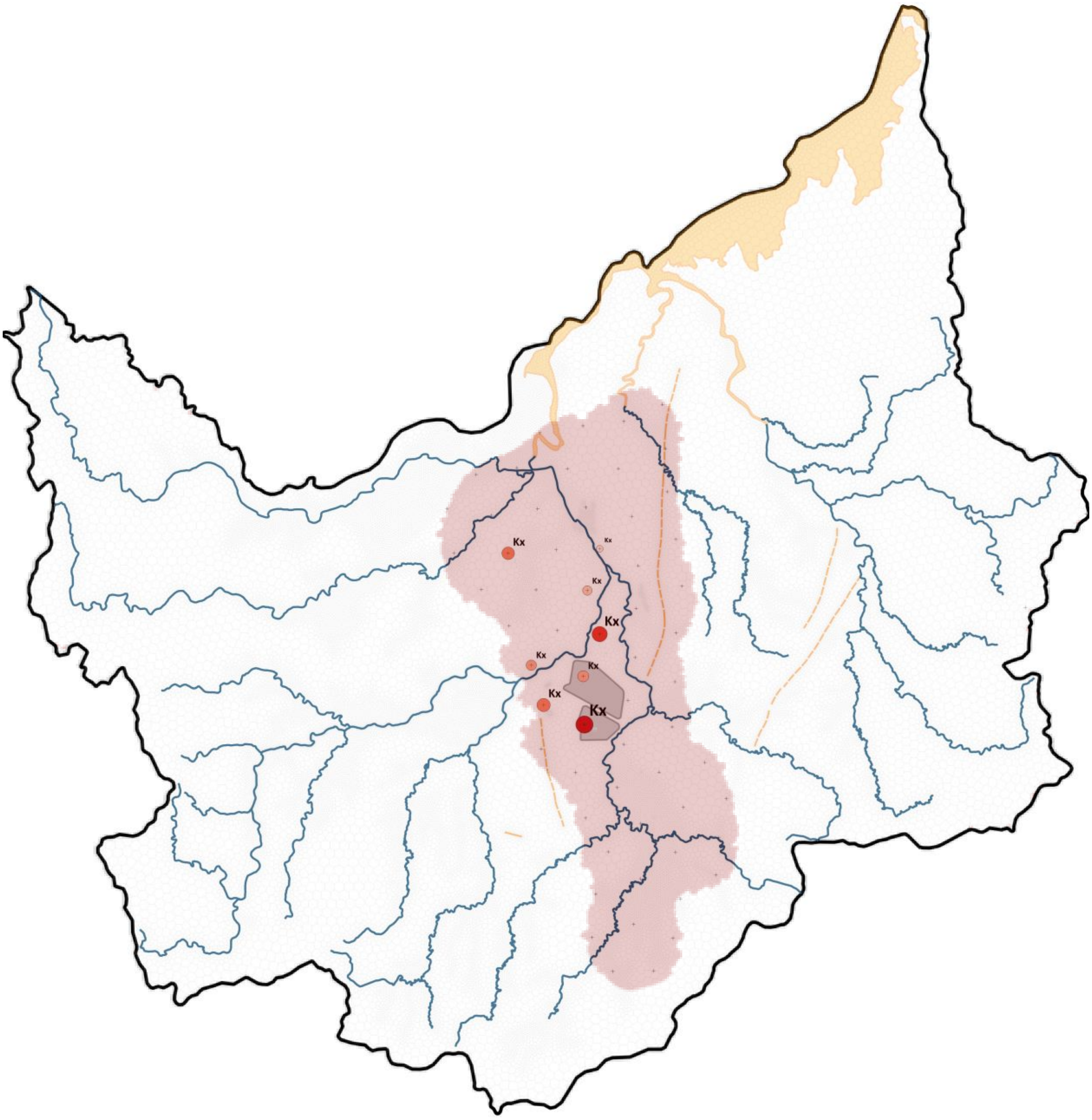

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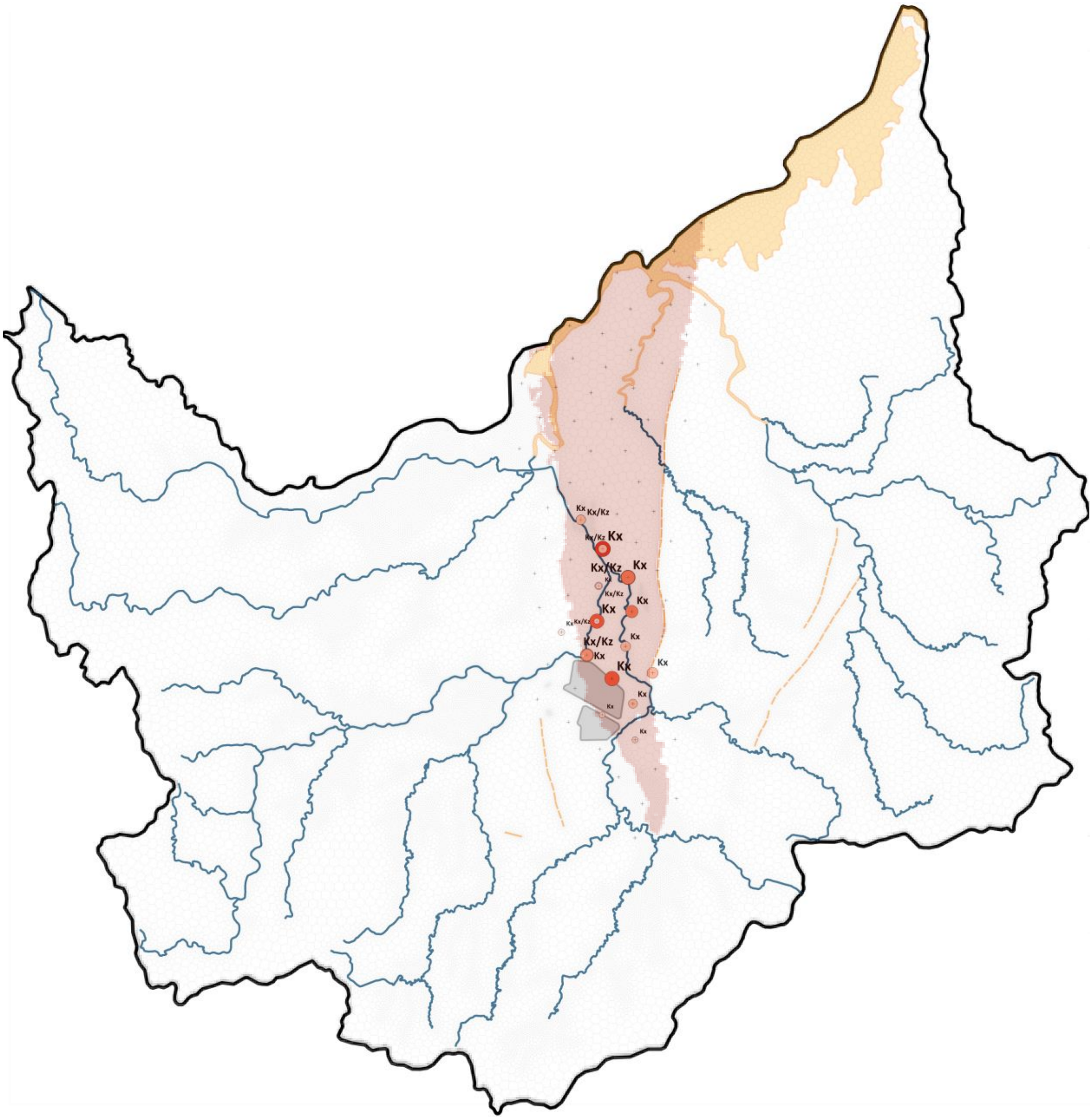

Layer 5 Parameter Identifiability
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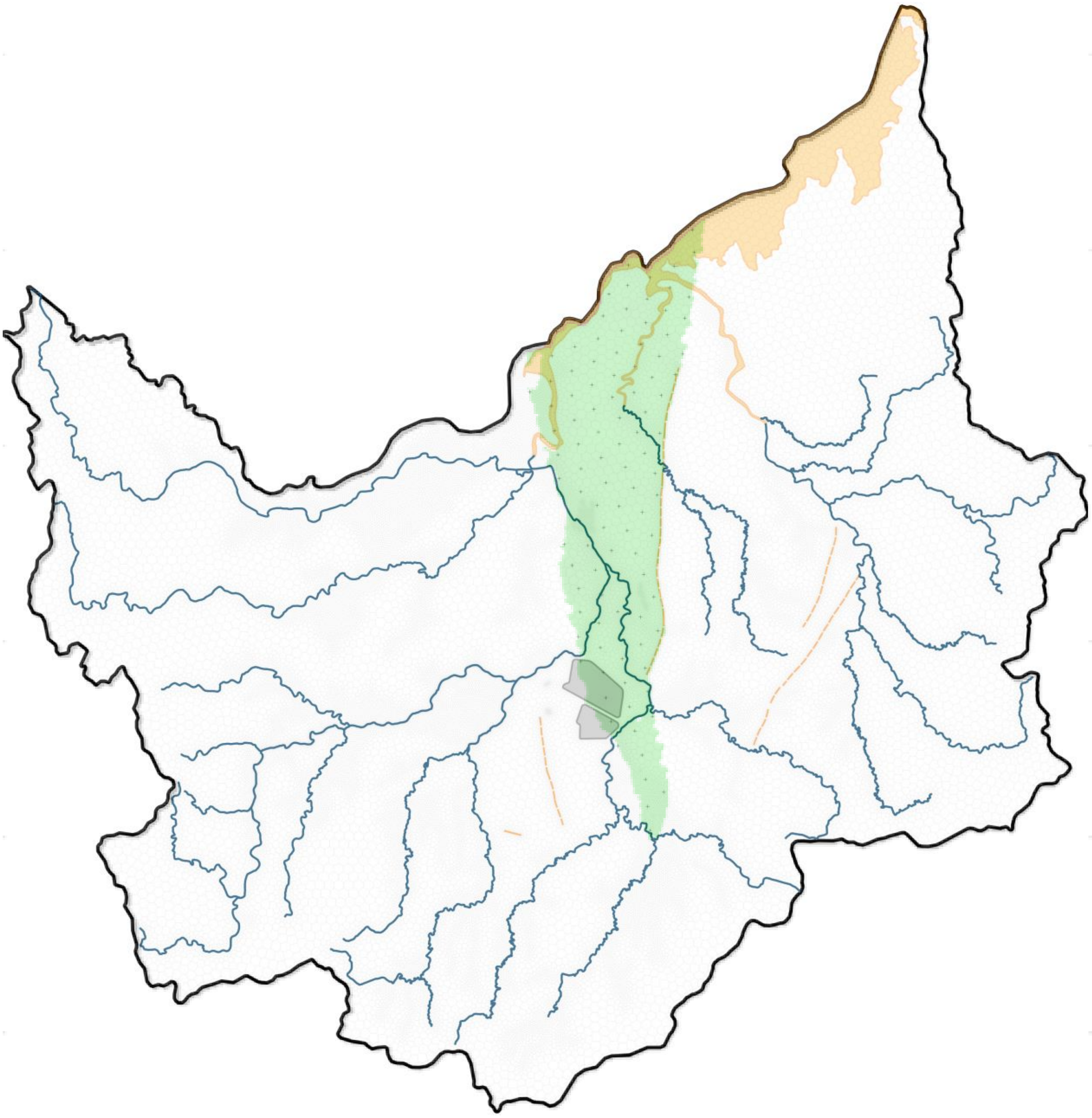
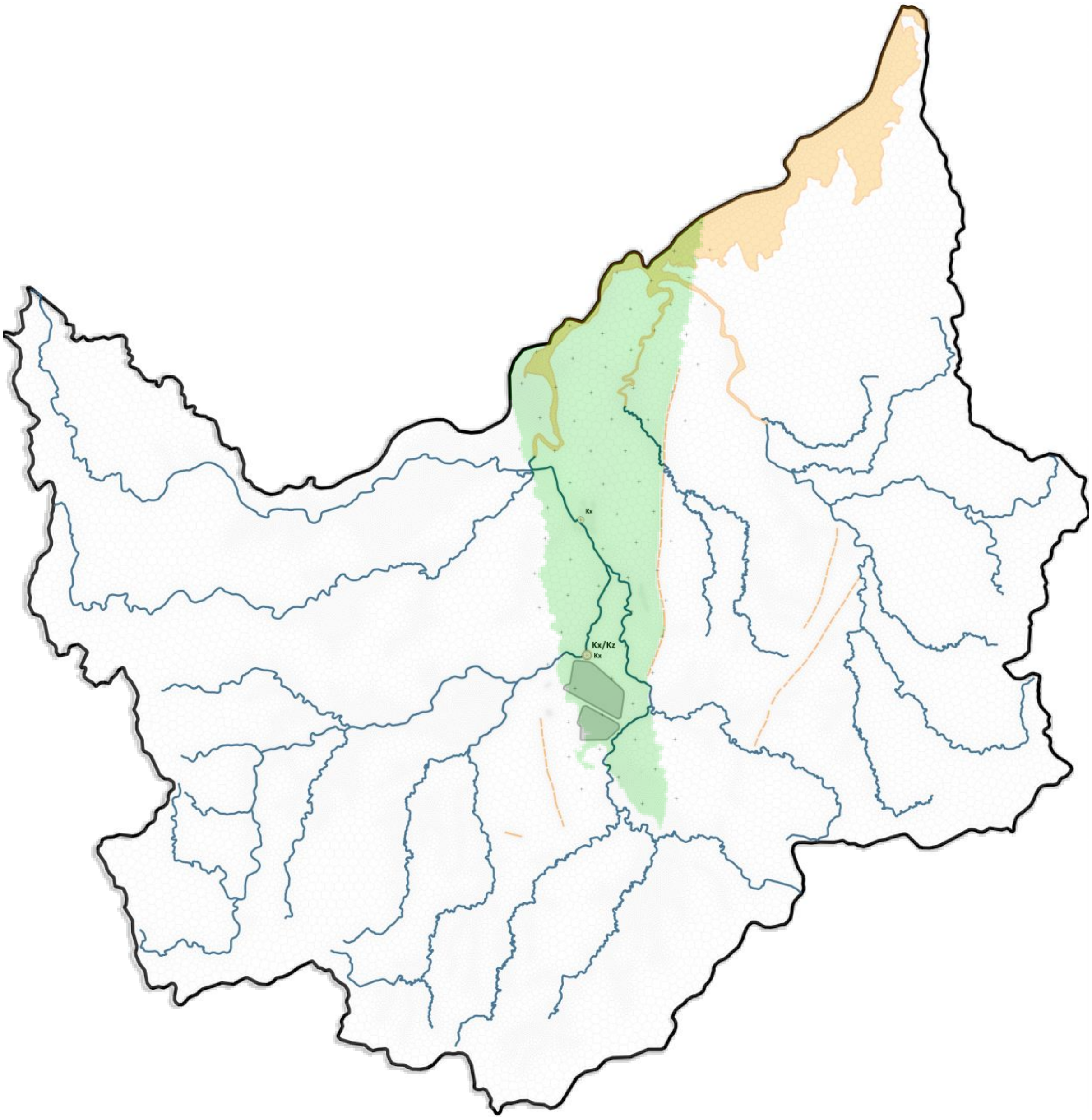


Layer 6 Parameter Identifiability
[‘+’ = <0.1; >0.1 – 1.0 with red circles increasing in relative size]



Layer 7 Parameter Identifiability
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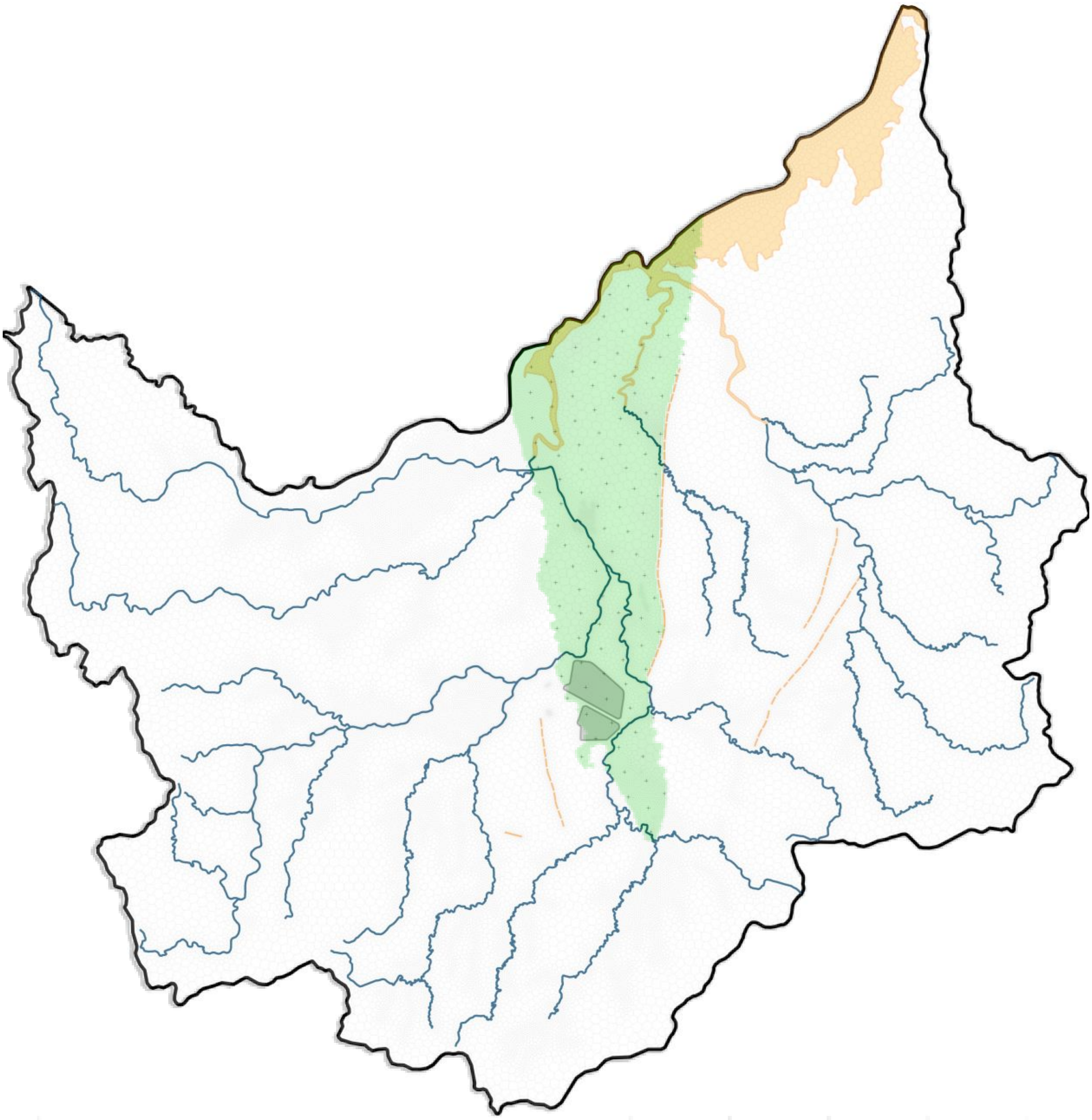

Layer 8 Parameter Identifiability
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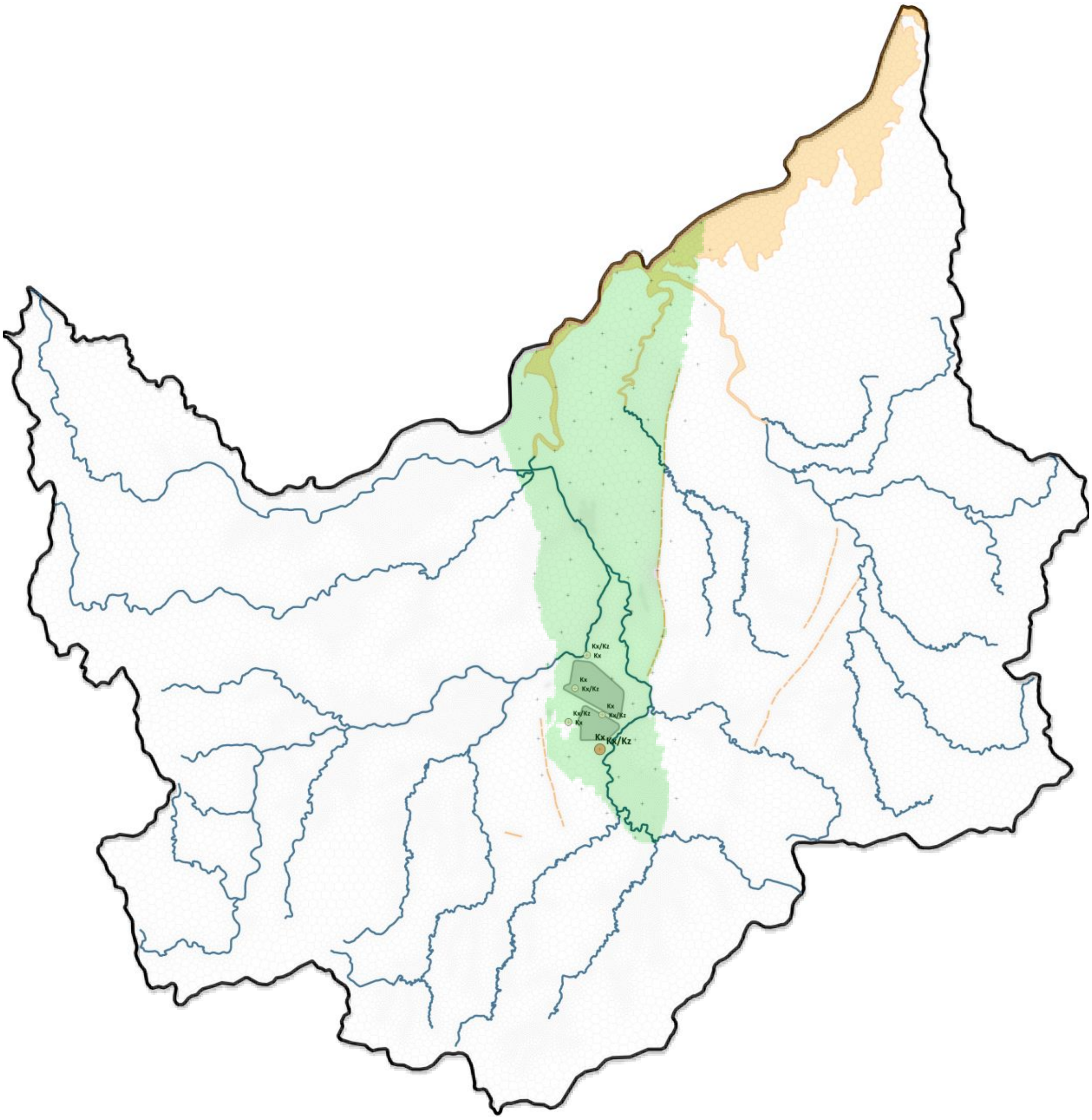

Layer 9 Parameter Identifiability
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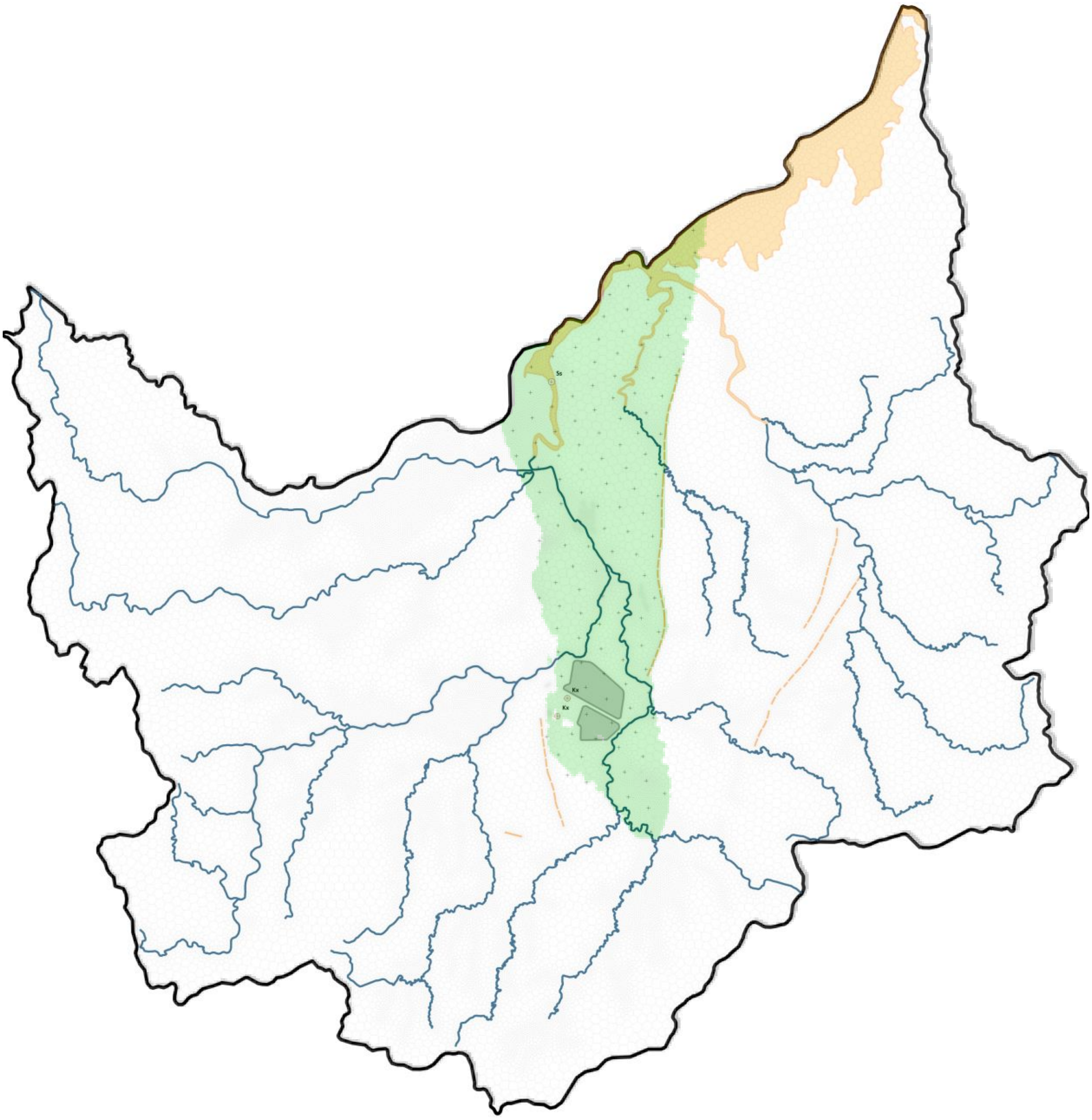

Layer 10 Parameter Identifiability
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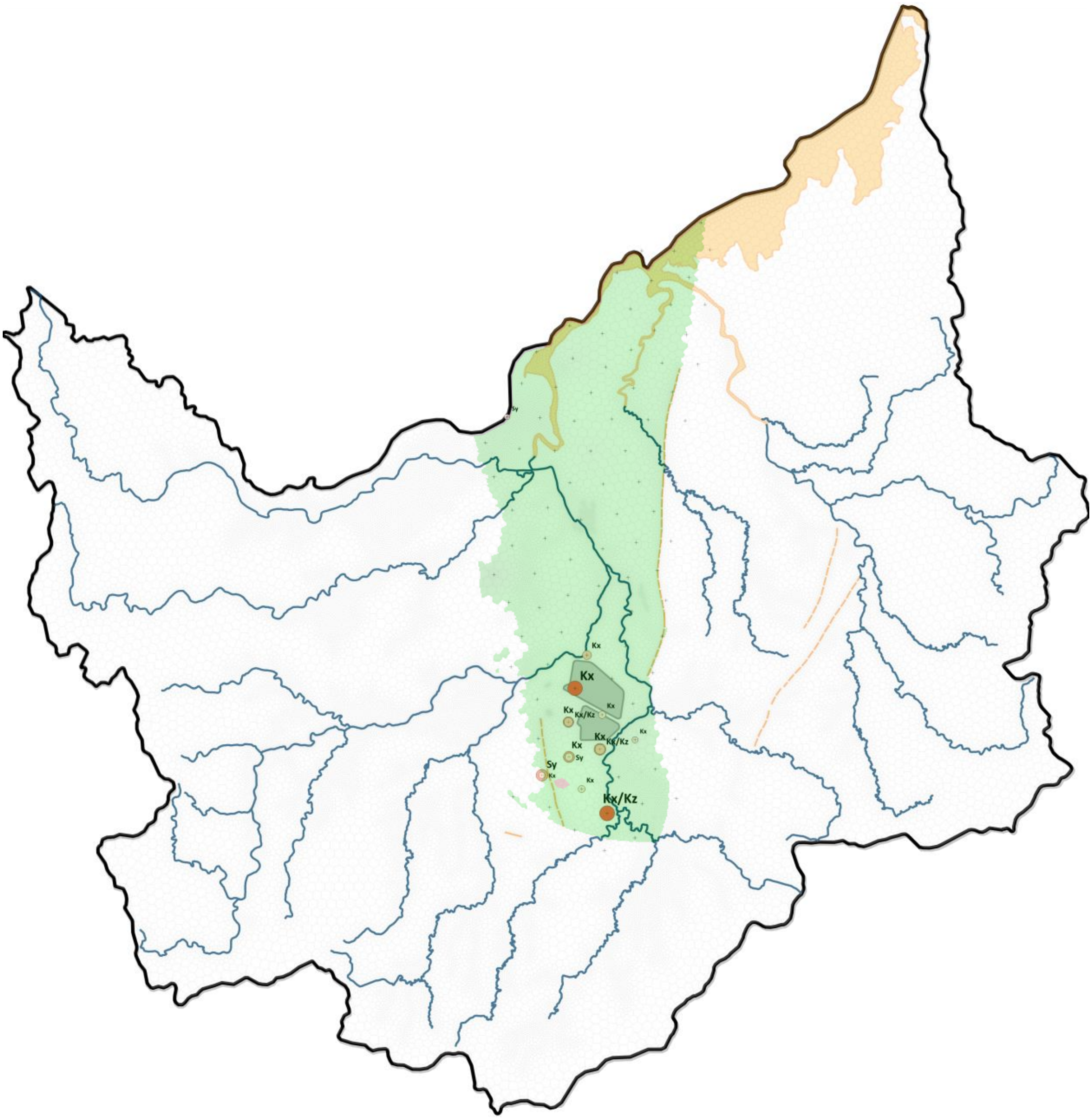

Layer 11 Parameter Identifiability
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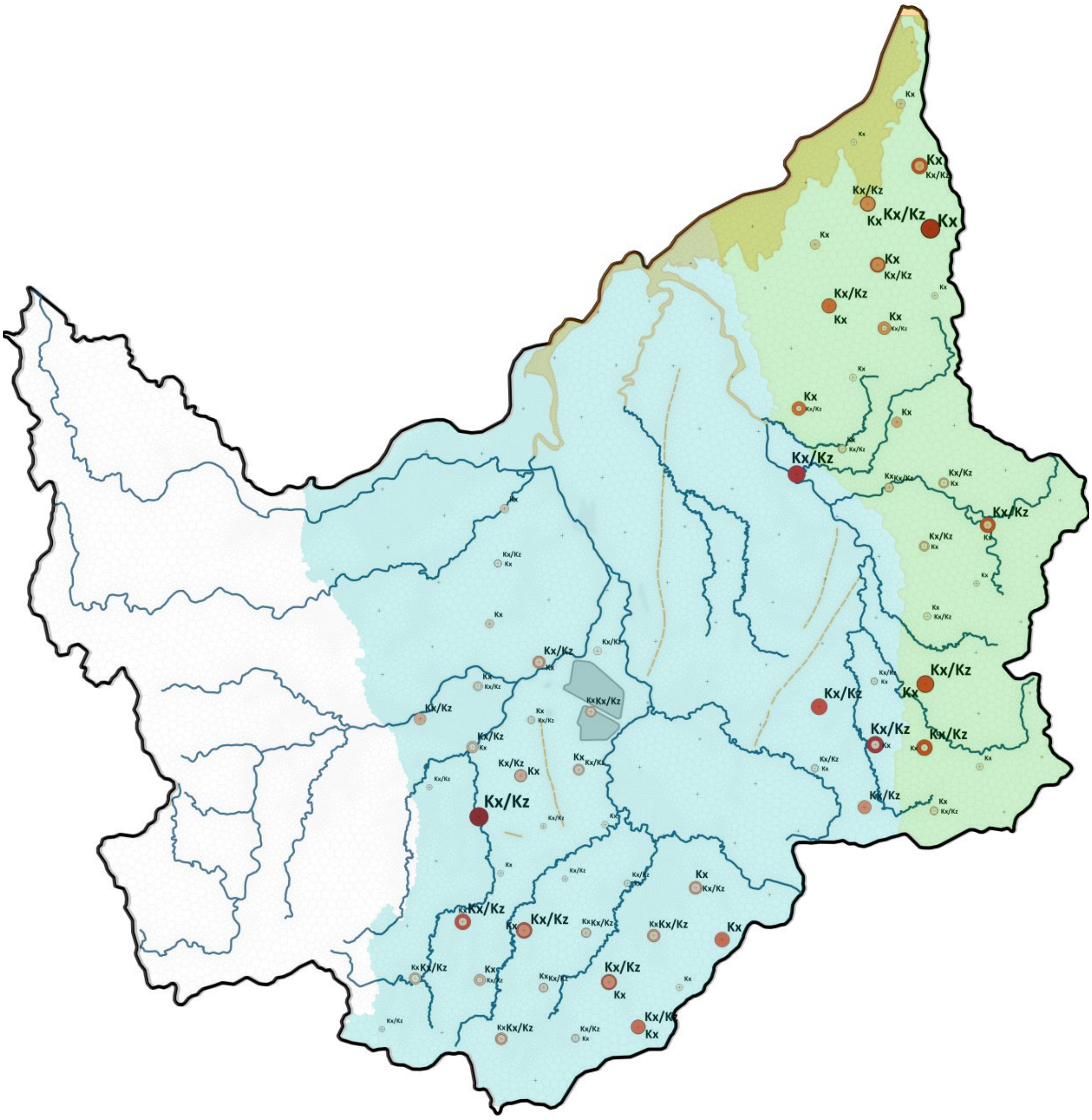

Layer 12 Parameter Identifiability
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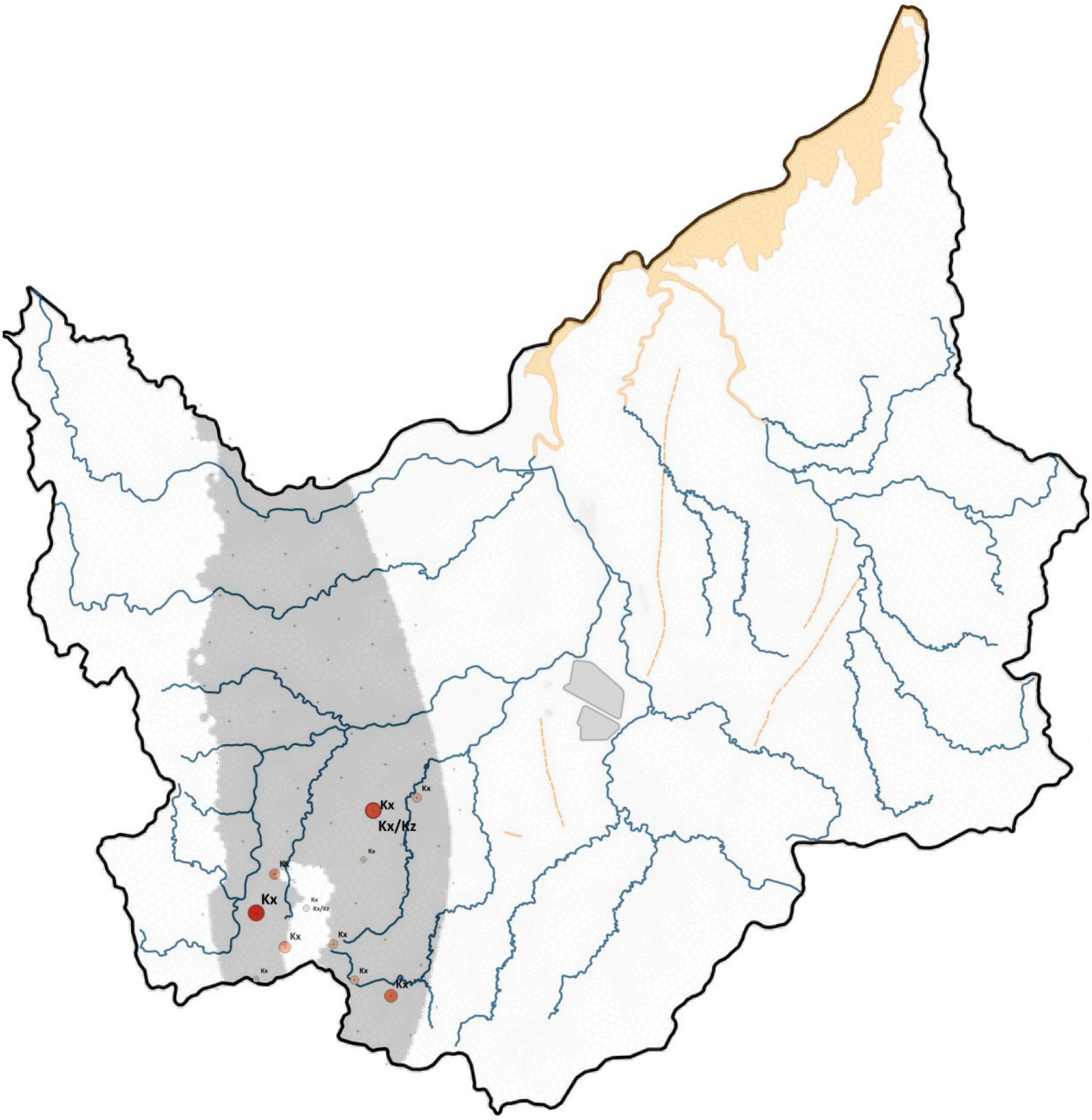

Layer 13 Parameter Identifiability
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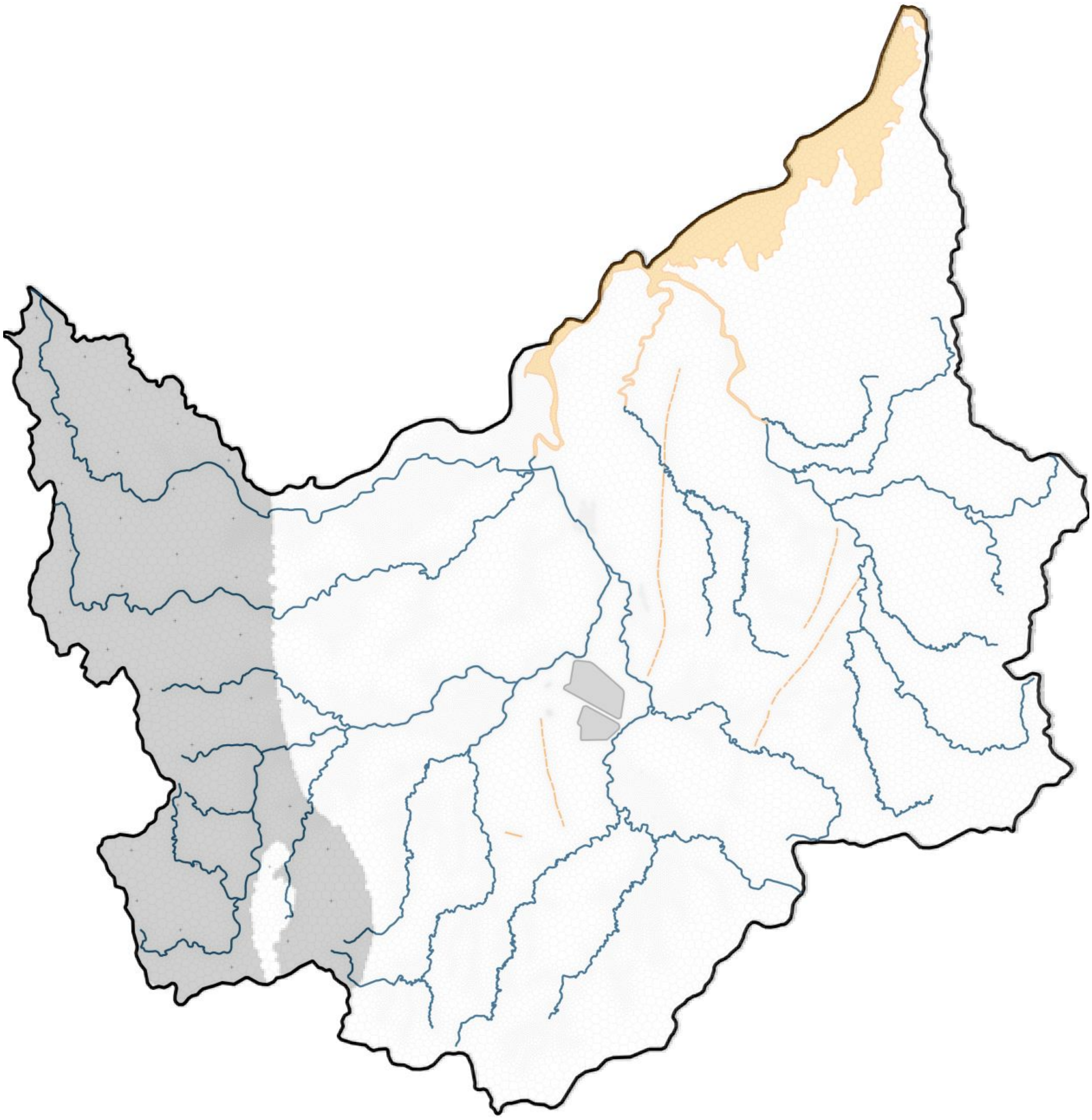

Layer 14 Parameter Identifiability
[‘+’ = <0.1; >0.1 – 1.0 with red circles increasing in relative size]

ATTACHMENT 17
PRESENTATION SLIDES TO DES ON 20 NOVEMBER 2019 AND 28 FEBRUARY 2020

Improvements to Numerical Groundwater Modelling

Central Qld Coal Project

Dr Damian Merrick
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Aaron Hagenbach
aaron@thehginstitute.com.au

Outline

1. Engagement
2. Peer Review Approach
3. Government Review Comments
4. Other Targeted Investigations (in Support of Model Improvements)
5. Uncertainty Analysis
6. Numerical Groundwater Model (Outcomes and Objectives)
7. Indicative Timeframes

Engagement

- **HydroAlgorithmics**
  - Dr Damian Merrick [*Lead Modeller developer of the AlgoCompute cloud software**]
  - Mr Aaron Hagenbach (THE HYDRO-GEOLOGie INSTITUTE [*The HGI*])
- Review of Qld Government and Commonwealth Government Comments
- Contemporary Numerical Groundwater Model and Assessment Report
- Technical Input to Responses to Government Comments

* Integral to the 1st IESC-Compliant Uncertainty Analysis

Peer Review Approach

- **AGE Consultants**
- IESC Information Guidelines – Explanatory Note (Uncertainty Analysis)
  - Fatal Flaws Review Checklist for Uncertainty Assessment
- Australian Groundwater Modelling Guidelines
  - Model Confidence Level Classification
- Peer Review Feedback to Recognise and Confirm:
  - Engagement History with Government Agencies
  - Uncertainty Analysis Methodology by HydroAlgorithmics
  - Numerical Groundwater Model Improvements and Other Investigations
  - Model Objectives / Outcomes

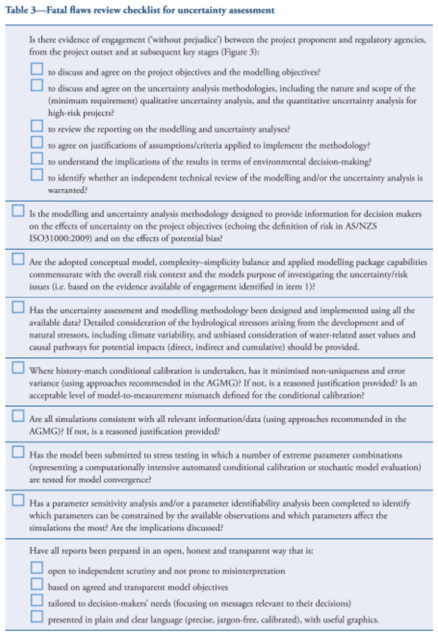


Table 3—Fatal flaws review checklist for uncertainty assessment

Is there evidence of engagement ('without prejudice') between the project proponent and regulatory agencies, from the project outset and at subsequent key stages (Figure 3):
- ☐ to discuss and agree on the project objectives and the modelling objectives?
- ☐ to discuss and agree on the uncertainty analysis methodologies, including the nature and scope of the (minimum requirement) qualitative uncertainty analysis, and the quantitative uncertainty analysis for high-risk projects?
- ☐ to review the reporting on the modelling and uncertainty analyses?
- ☐ to agree on justifications of assumptions/criteria applied to implement the methodology?
- ☐ to understand the implications of the results in terms of environmental decision-making?
- ☐ to identify whether an independent technical review of the modelling and/or the uncertainty analysis is warranted?

☐ Is the modelling and uncertainty analysis methodology designed to provide information for decision makers on the effects of uncertainty on the project objectives (echoing the definition of risk in AS/NZS ISO31000:2009) and on the effects of potential bias?

☐ Are the adopted conceptual model, complexity–simplicity balance and applied modelling package capabilities commensurate with the overall risk context and the models purpose of investigating the uncertainty/risk issues (i.e. based on the evidence available of engagement identified in item 1)?

☐ Has the uncertainty assessment and modelling methodology been designed and implemented using all the available data? Detailed consideration of the hydrological stressors arising from the development and of natural stressors, including climate variability, and unbiased consideration of water-related asset values and causal pathways for potential impacts (direct, indirect and cumulative) should be provided.

☐ Where history-match conditional calibration is undertaken, has it minimised non-uniqueness and error variance (using approaches recommended in the AGMG)? If not, is a reasoned justification provided? Is an acceptable level of model-to-measurement mismatch defined for the conditional calibration?

☐ Are all simulations consistent with all relevant information/data (using approaches recommended in the AGMG)? If not, is a reasoned justification provided?

☐ Has the model been submitted to stress testing in which a number of extreme parameter combinations (representing a computationally intensive automated conditional calibration or stochastic model evaluation) are tested for model convergence?

☐ Has a parameter sensitivity analysis and/or a parameter identifiability analysis been completed to identify which parameters can be constrained by the available observations and which parameters affect the simulations the most? Are the implications discussed?

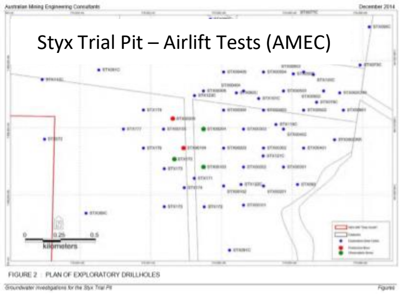
Have all reports been prepared in an open, honest and transparent way that is:
- ☐ open to independent scrutiny and not prone to misinterpretation
- ☐ based on agreed and transparent model objectives
- ☐ tailored to decision-makers' needs (focusing on messages relevant to their decisions)
- ☐ presented in plain and clear language (precise, jargon-free, calibrated), with useful graphics.

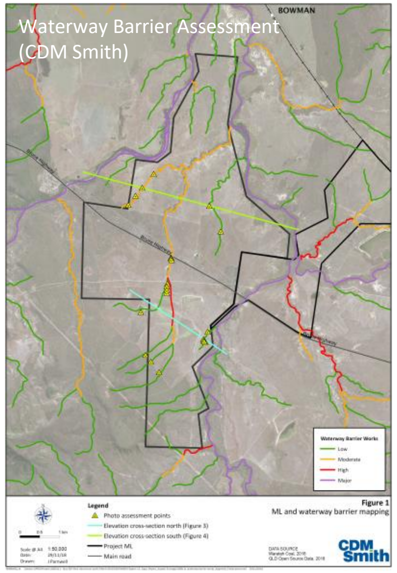
Government Review Comments

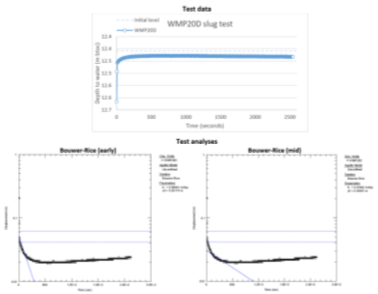
- Key Groundwater-Related Review Comments* / Advice:
  - Qld Department of Environment and Science (DES) (Revised August 2019)
  - Qld Department of Agriculture and Fisheries (DAF) (14 June 2019)
  - Commonwealth Department of Environment and Energy (DoEE) (14 June 2019)
  - IESC Advice (IESC 2018-094) [including IESC 2017-091] (31 July 2018)
- EIS Groundwater Model Uncertainty and Related Assessments (***Connectivity with Groundwater***):
  - Potential Impact of Groundwater Drawdown (during and post-mining)
  - Baseflow / Leakage from Creeks and In-stream Pools
  - Riparian GDEs / Wetland Function
  - Tidal / Seawater Interface

**NB: GHD Pty Ltd also provided Independent [Non-Government] Third Party Review Comments (20 December 2018)*

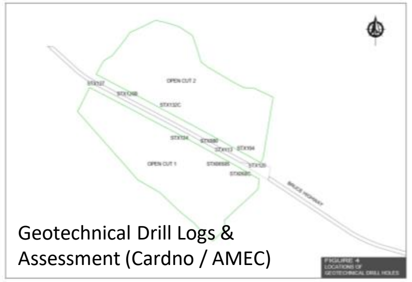
Previous Investigations



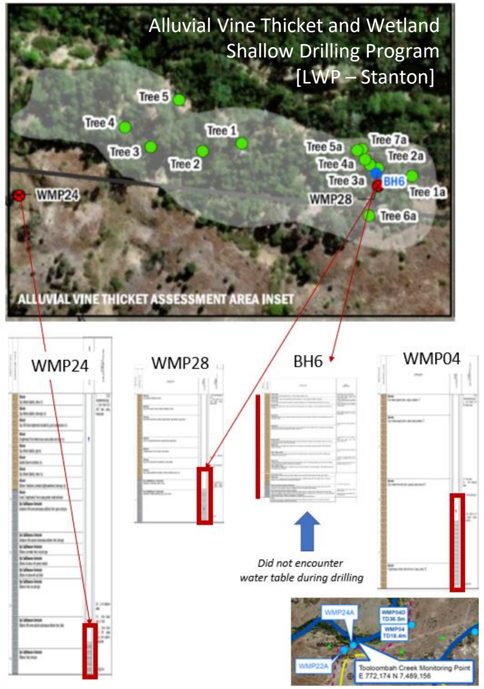




Aquifer Tests – Falling Head / Rising Head
[73 Estimations / 31 Locations]



Geotechnical Drill Logs &
Assessment (Cardno / AMEC)



Exploration Drilling Programs
(Waratah Coal)

2018 Geological Model
(Waratah Coal)

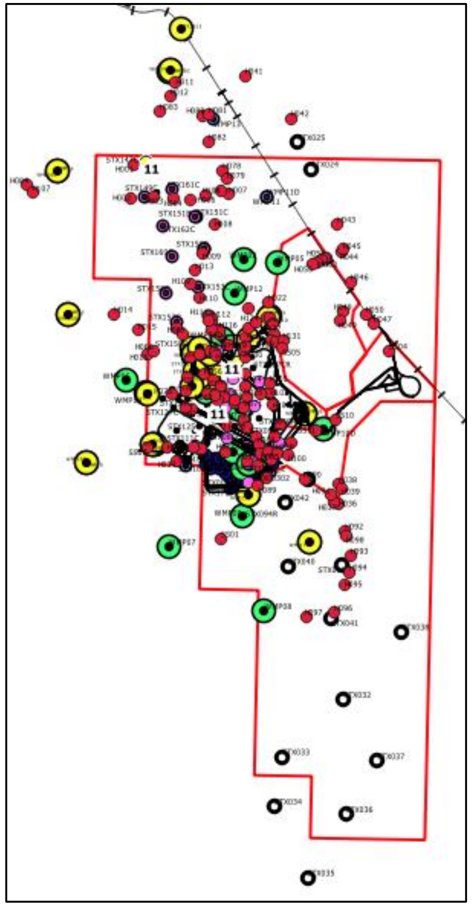
Geochemical Testwork
(RGS & ALS) – 195 Samples

Soil Sampling
(Horizon Soil & Evaluation)
- 145 Samples

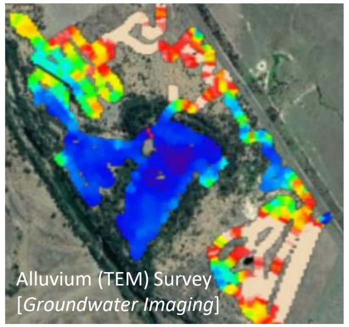
WMP02-15 Groundwater
Monitoring Network
(CDM Smith)

WMP16-30 Groundwater
Monitoring Network
(CDM Smith)

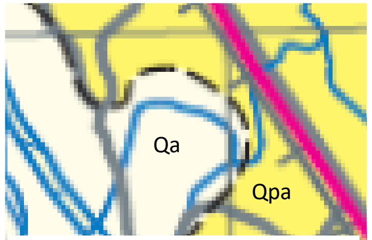
Well Completion Reports
(Arrow Energy NL)



Other Targeted Investigations



Alluvium (TEM) Survey [*Groundwater Imaging*]

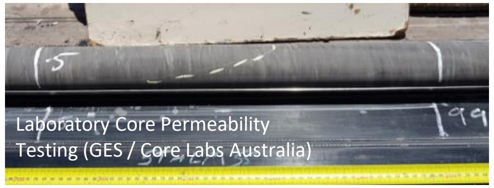


Geomorphology [*Fluvial Systems*] & Surficial Geology Review (Qa, Qpa)

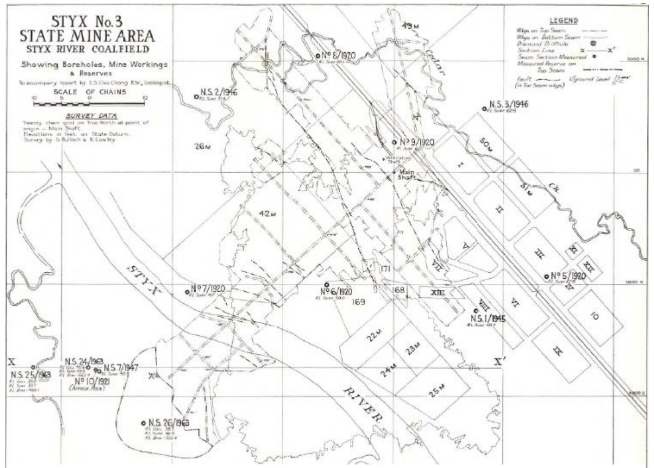
Permeability Packer Testing [*AMEC*]

Ogmore Road Bridge Styx River Tide Level Measurements

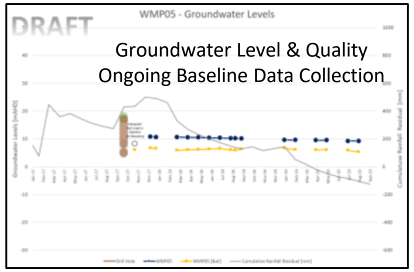
AWS (Mamelon)



Laboratory Core Permeability Testing (GES / Core Labs Australia)



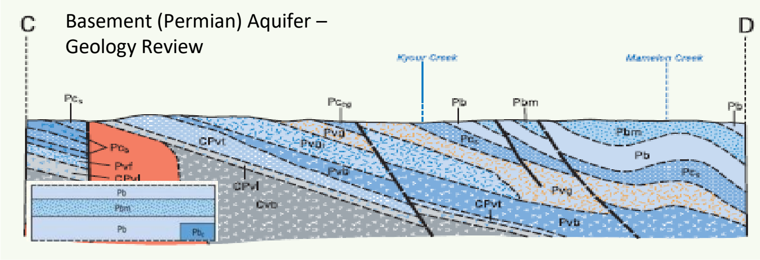
Styx River Coalfield Review of Historical Mining & Cumulative Assessment (Styx No.1, No.2, No.3 & Bowman Coal Mine



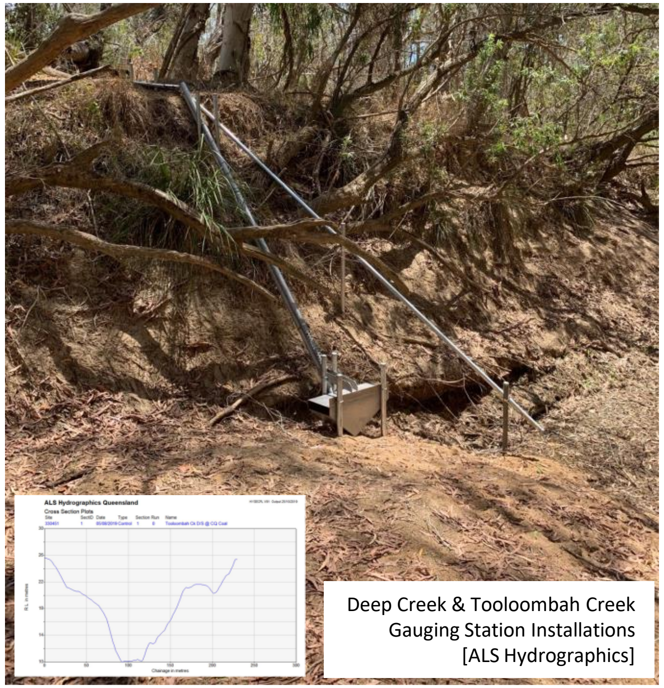
Groundwater Level & Quality Ongoing Baseline Data Collection

Alluvium GMP Dataloggers Styx River, Tooloombah & Deep Creeks [GES]

Example Photo (GES)



Basement (Permian) Aquifer – Geology Review



Deep Creek & Tooloombah Creek Gauging Station Installations [ALS Hydrographics]

Uncertainty Analysis

- Combination of Monte Carlo and Scenario-based Analyses*
  - Tidal Boundary Condition Range (incorporating Sea Level Rise Predictions).
  - Rainfall Recharge Totals (incorporating Climate Change Scenario Range and Adopted Alluvium / Regolith (%) Recharge).
  - Maximum ET Rate and Extinction Depths.
  - Hydraulic Conductivity Zones (Pilot Points) – Alluvium / Styx Interburden / Coal Seams / Basement Aquifer (Vertical & Horizontal).
  - Geological Structure (Fault) Zone of Hydraulic Conductivity [Enhanced or Reduced].
  - Depth Dependence (Depth Function) in Coal Seams.
  - Specific Storage and Specific Yield Parameters.
  - Spoil Properties in Backfilled Voids.
  - Predictive Sensitivity for Increased Landholder Pumping.

**Preliminary List Only - Subject to Change Based on Prediction Model Outcomes*

Numerical Groundwater Model

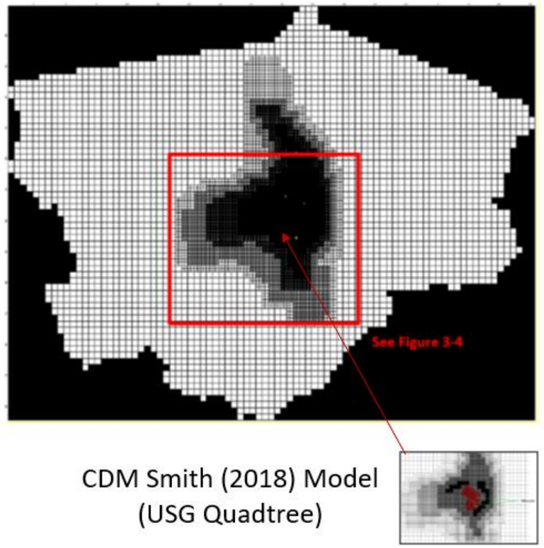
- Approach and Targeted Improvements*

Model Domain / Dimensions [*Extension to FHA-047*]	☑	Prediction Period [*Refinement for Maximum Extent*]	☑
Model Layers / Properties [*Separation, Aggregation & Partitioning for Anisotropy*]	☑	Prediction Period Temporal Discretisation [*Consistent Application*]	☑
Model Geometry and Mesh Design [*Refinement & Delineation for GDE Analysis*]	☑	Temporal Parameter Variability [*TVM Application*]	☑
Geological Structure / Faults [*Analysis*]	☑	Recovery Period [+*100 Year Analysis*]	☑
Model Boundary Conditions [*Refinement & Analysis for Tidal / Seawater Interface*]	☑	Cumulative Assessment [*Historic Workings Depressurisation and Recovery*]	☑
Model Drains [*Refinements and Additional Coverage*]	☑	Uncertainty Analysis / Sensitivity Analysis	☑
Spatial Parameter Variability [*Refinements & Partitioning for Cenozoic Sediments ET Extinction Depths/Rates*]	☑	Recommendations for Mitigation and Future Monitoring including Adaptive Program Investigations	☑
Steady State Calibration	☑	Licensing Volume Estimates [*EP Act and Water Act*]	☑
Transient Calibration Period [*Extension for All Datasets*]	☑	Reporting [*Reconciliation of Government Comments*]	☑

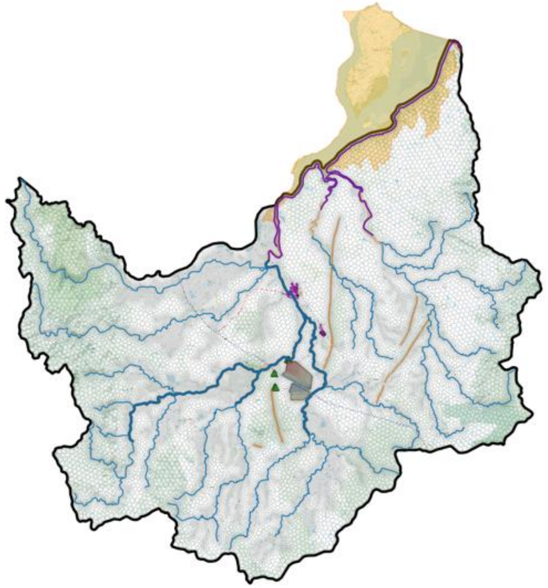
**Subject to Ongoing Review and Refinement during Numerical Groundwater Model Build/Calibration (In Progress)*

Indicative Timeframes

- Numerical Groundwater Model and Assessment – 1st Quarter 2020
- Groundwater-Related Responses to Government Review Comments – 2nd Quarter 2020



CDM Smith (2018) Model
(USG Quadtree)



HydroAlgorithmics Model
(USG - AlgoMesh)

Thank You

Update to Improvements to Numerical Groundwater Modelling

Central Qld Coal Project

Dr Damian Merrick
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Aaron Hagenbach
aaron@thehginstitute.com.au

Outline

1. Last Meeting Recap (20 November 2019)
2. Model Improvement Progress
3. Key Next Step - Uncertainty Analysis

Last Meeting Recap

- Approach and Targeted Improvements

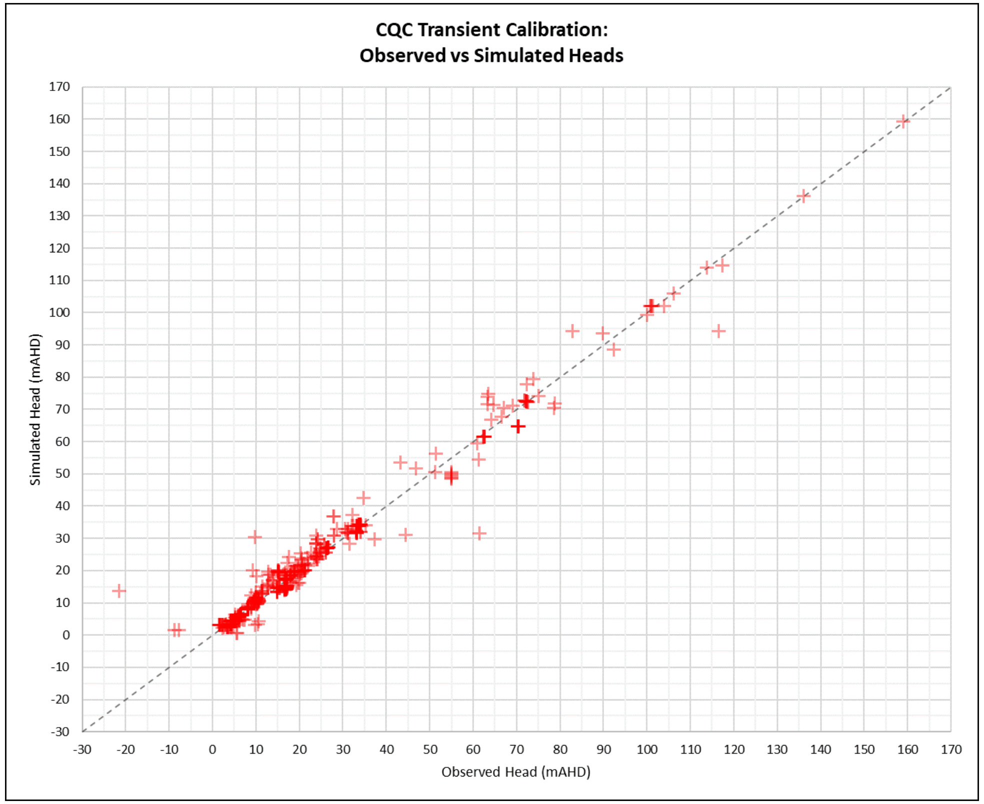
Model Domain / Dimensions [*Extension to FHA-047*]	☑	Prediction Period [*Refinement for Maximum Extent*]	☑
Model Layers / Properties [*Separation, Aggregation & Partitioning for Anisotropy*]	☑	Prediction Period Temporal Discretisation [*Consistent Application*]	☑
Model Geometry and Mesh Design [*Refinement & Delineation for GDE Analysis*]	☑	Temporal Parameter Variability [*TVM Application*]	☑
Geological Structure / Faults [*Analysis*]	☑	Recovery Period [*+500 Year Analysis*]	☑
Model Boundary Conditions [*Refinement & Analysis for Tidal / Seawater Interface*]	☑	Cumulative Assessment [*Historic Workings Depressurisation and Recovery*]	☑
Model Drains [*Refinements and Additional Coverage*]	☑	Uncertainty Analysis / Sensitivity Analysis	☑
Spatial Parameter Variability [*Refinements & Partitioning for Cenozoic Sediments ET Extinction Depths/Rates*]	☑	Recommendations for Mitigation and Future Monitoring including Adaptive Program Investigations	☑
Steady State Calibration	☑	Licensing Volume Estimates [*EP Act and Water Act*]	☑
Transient Calibration Period [*Extension for All Datasets*]	☑	Reporting [*Reconciliation of Government Comments*]	☑

Model Improvement Progress

- Extended Baseline Datasets for Calibration (and Future Validation)
- Model Confidence Classification Level – Staged Peer Review
- Uncertainty Analysis
- Key Outputs for GDE Assessment and Management Plan (Draft)

Model Improvement Progress

- Extended Baseline Datasets for Calibration



>1,000 Groundwater Head Measurements in Model Domain
- **38 exploration drill holes with level records (STX series)**
- **6 shallow drill holes - Potential GDEs (BH1-BH6)**
- **47 groundwater monitoring network bores (WMP Series)**
- **30 landholder bore survey records**
- **69 other registered bores on the Government database**

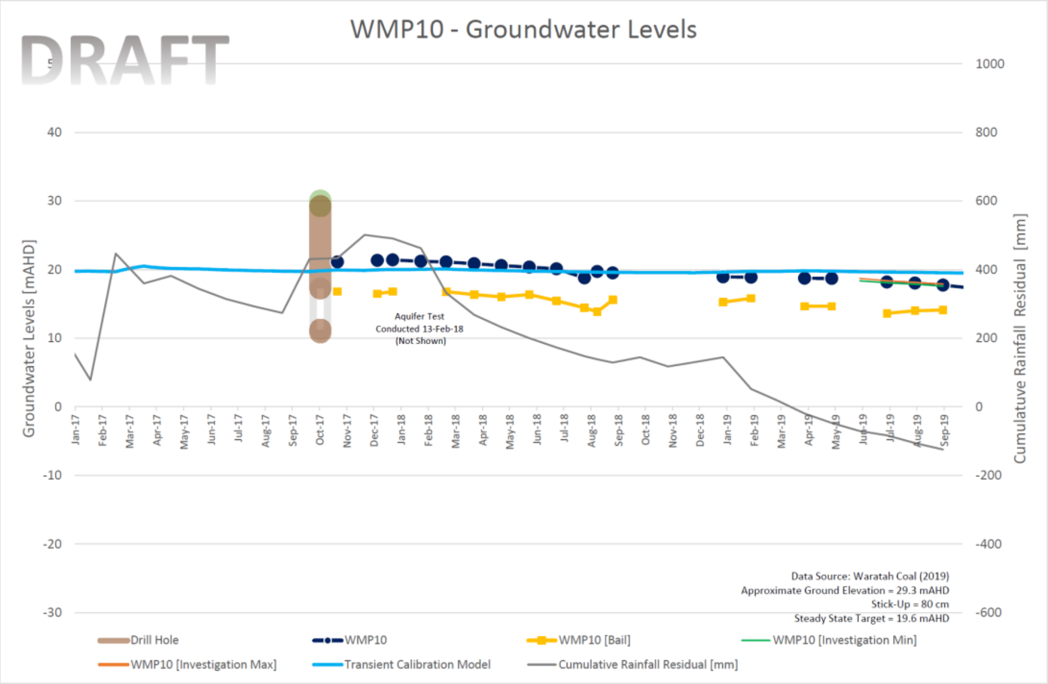
Scaled RMS (SRMS) errors (3.49% and 2.01%) [<10%]

Mass Balance (Maximum Cumulative)
Closure Errors (<0.01% and 0.08%) [<0.5%]

Steady State and Transient Model Runs are Acceptable.
Calibrated to Groundwater Heads (History-Matched) ☑

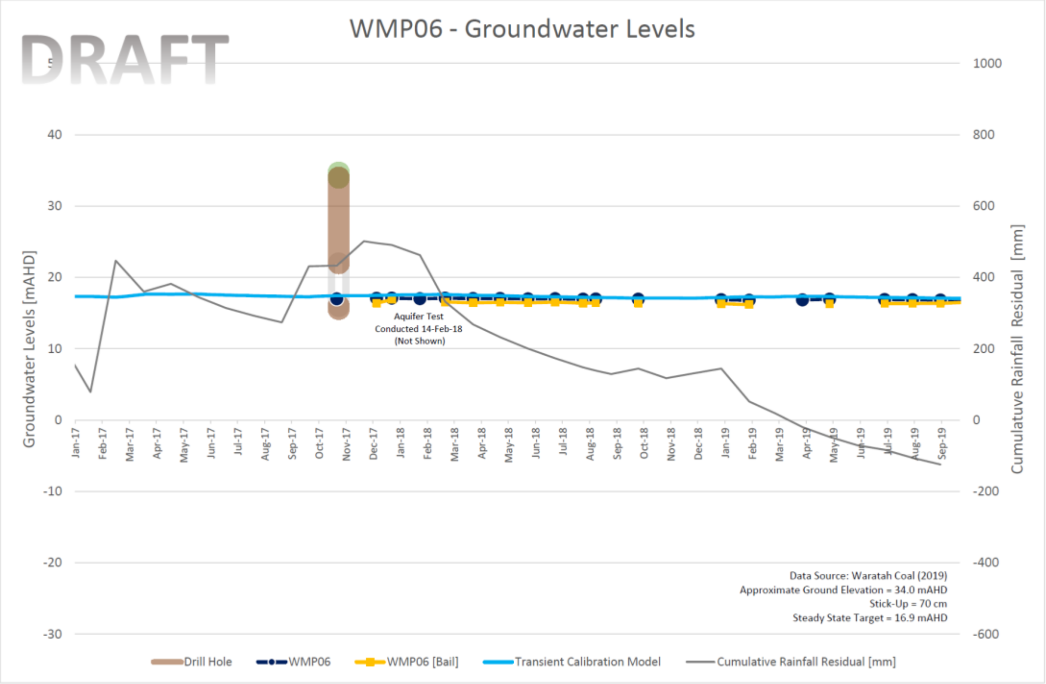
Modelled 1,666 pilot points in total, with 7,056 parameters.

Model Improvement Progress



WMP10 - Groundwater Levels

Data Source: Waratah Coal (2019)
Approximate Ground Elevation = 29.3 mAHD
Stick-Up = 80 cm
Steady State Target = 19.6 mAHD

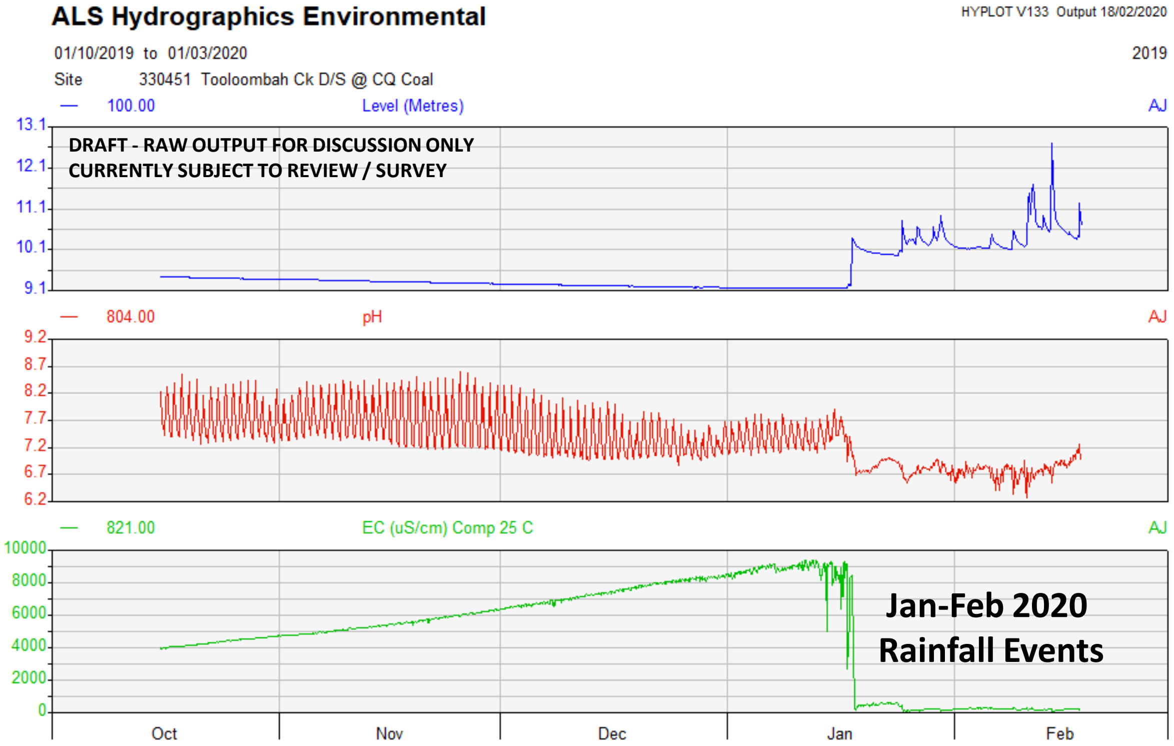


WMP06 - Groundwater Levels

Data Source: Waratah Coal (2019)
Approximate Ground Elevation = 34.0 mAHD
Stick-Up = 70 cm
Steady State Target = 16.9 mAHD

Model Improvement Progress

- Baseline Data Collection for Future Validation



ALS Hydrographics Environmental

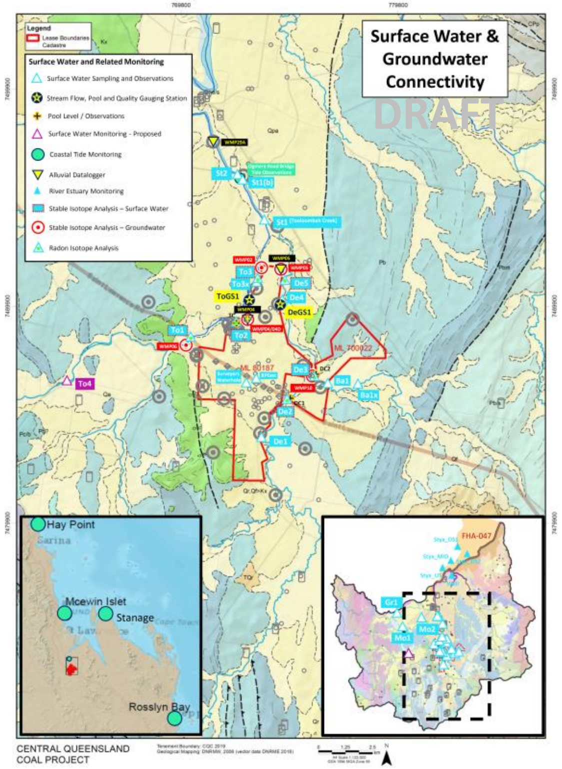
HYPLOT V133 Output 18/02/2020

01/10/2019 to 01/03/2020 2019

Site 330451 Tooloombah Ck D/S @ CQ Coal

DRAFT - RAW OUTPUT FOR DISCUSSION ONLY
CURRENTLY SUBJECT TO REVIEW / SURVEY

Jan-Feb 2020
Rainfall Events



Model Improvement Progress

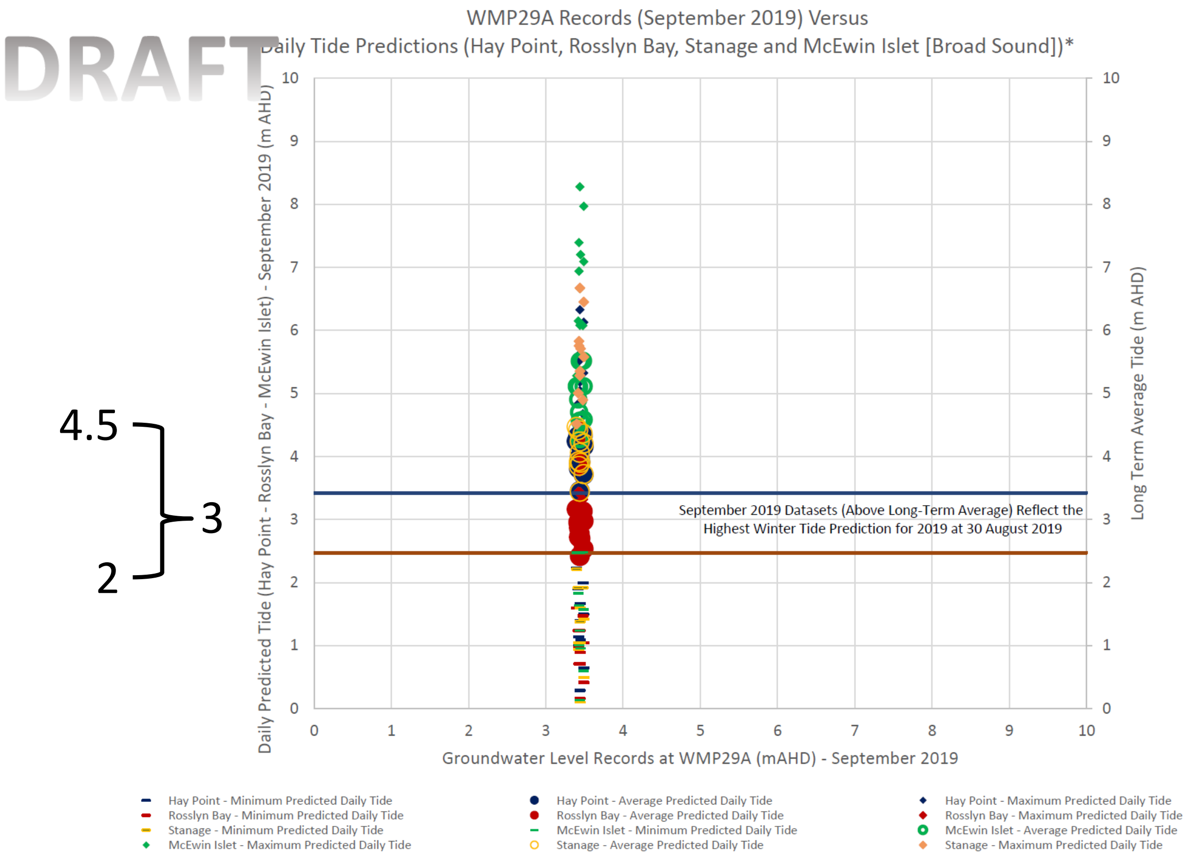
- Model Confidence Classification Level – Staged Peer Review
- **AGE Consultants (Stages 1 & 2 of 4)**
- Australian Groundwater Modelling Guideline Checklist
- IESC Information Guidelines – Explanatory Note (Uncertainty Analysis)
- Fatal Flaws Review Checklist for Uncertainty Assessment

Uncertainty Analysis

- Combination of Monte Carlo and Scenario-based Analyses*
  - Tidal Boundary Condition Range (incorporating Sea Level Rise Predictions).
  - Rainfall Recharge Totals (incorporating Climate Change Scenario Range and Adopted Alluvium / Regolith (%) Recharge).
  - Maximum ET Rate and Extinction Depths.
  - Hydraulic Conductivity Zones (Pilot Points) – Alluvium / Styx Interburden / Coal Seams / Basement Aquifer (Vertical & Horizontal).
  - Geological Structure (Fault) Zone of Hydraulic Conductivity [Enhanced or Reduced].
  - Depth Dependence (Depth Function) in Coal Seams.
  - Specific Storage and Specific Yield Parameters.
  - Spoil Properties in Backfilled Voids.
  - Predictive Sensitivity for Increased Landholder Pumping.

**Final Scenarios Currently Subject to Peer Review and May Change*

Uncertainty Analysis



* Average daily tide for September 2019 based on midpoint analysis for 2 x minimum and 2 maximum predicted daily tides

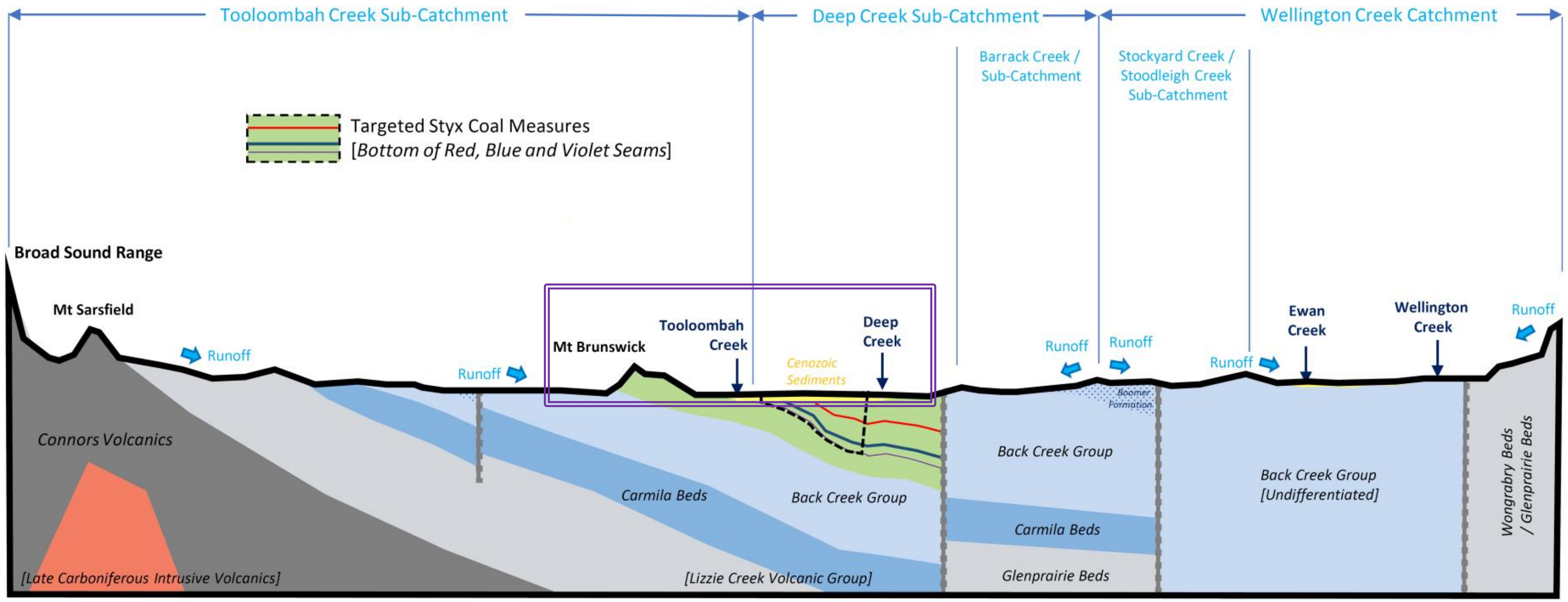
Peer Review AGE Consultants:

> *‘The surface processes in the tidal zone of Styx River are dynamic, however on the timeframes that the groundwater model operates it is entirely appropriate to represent this as a constant head.’*

NB: Qld Government adopted planning projection of 0.8 m sea level rise by 2100, considers the IPCC Fifth Assessment Report.

Model Improvement Progress

- Key Outputs for GDE Assessment and Management Plan (Draft)



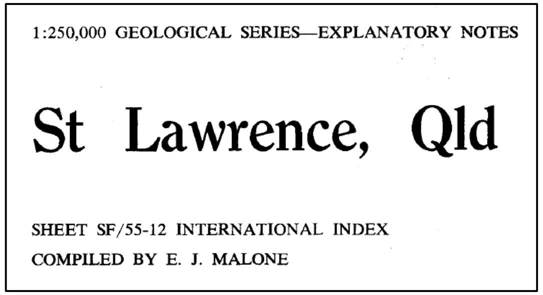
Simplified Groundwater Conceptual Model – West-East Section

[Indicative Only, Not to Scale]

NB: Faults are shown as vertical for purposes of conceptualisation.

Numerical Groundwater Model

Source: After



1:250,000 GEOLOGICAL SERIES—EXPLANATORY NOTES

St Lawrence, Qld

SHEET SF/55-12 INTERNATIONAL INDEX
COMPILED BY E. J. MALONE

[With Annotations]

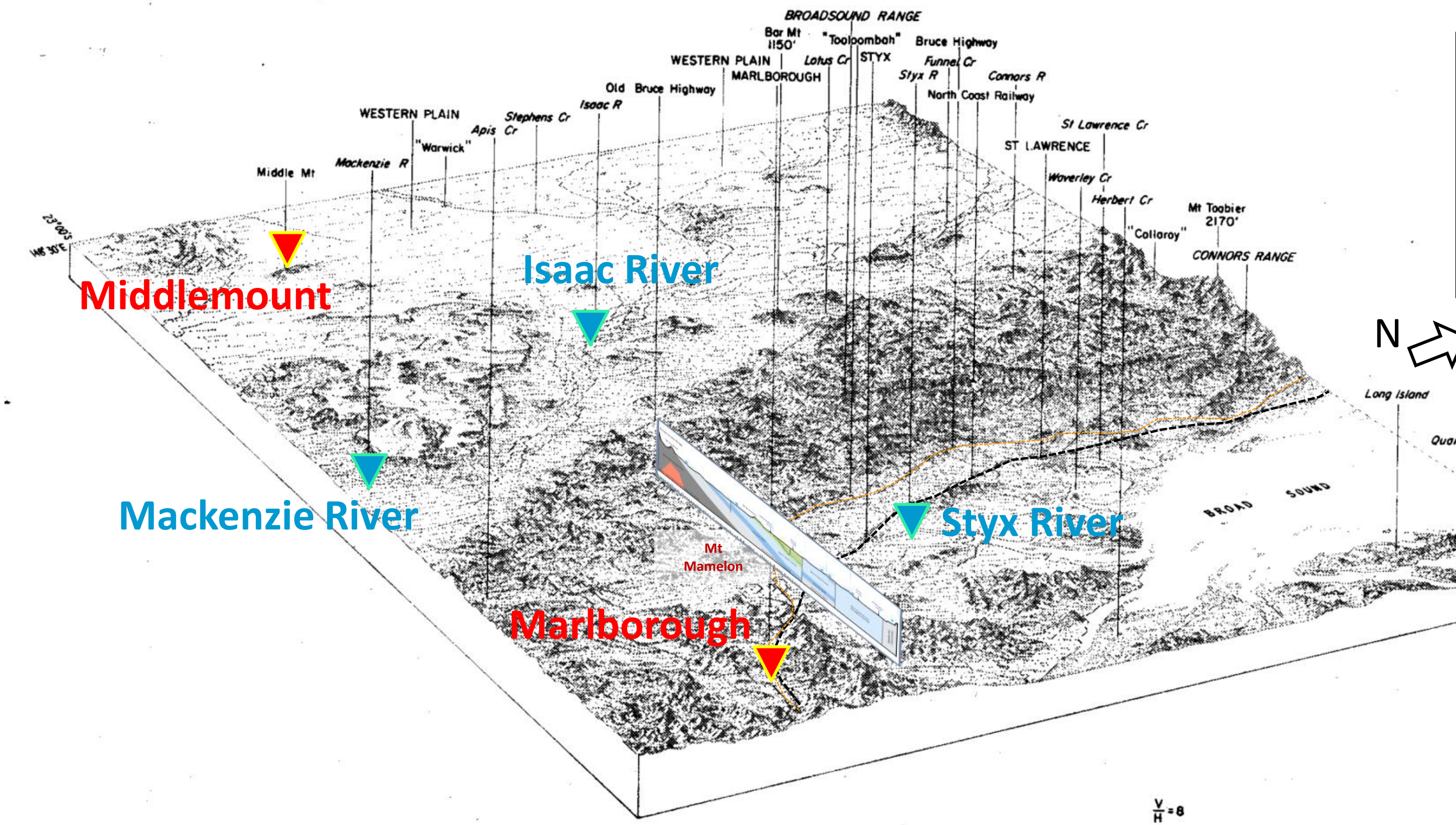
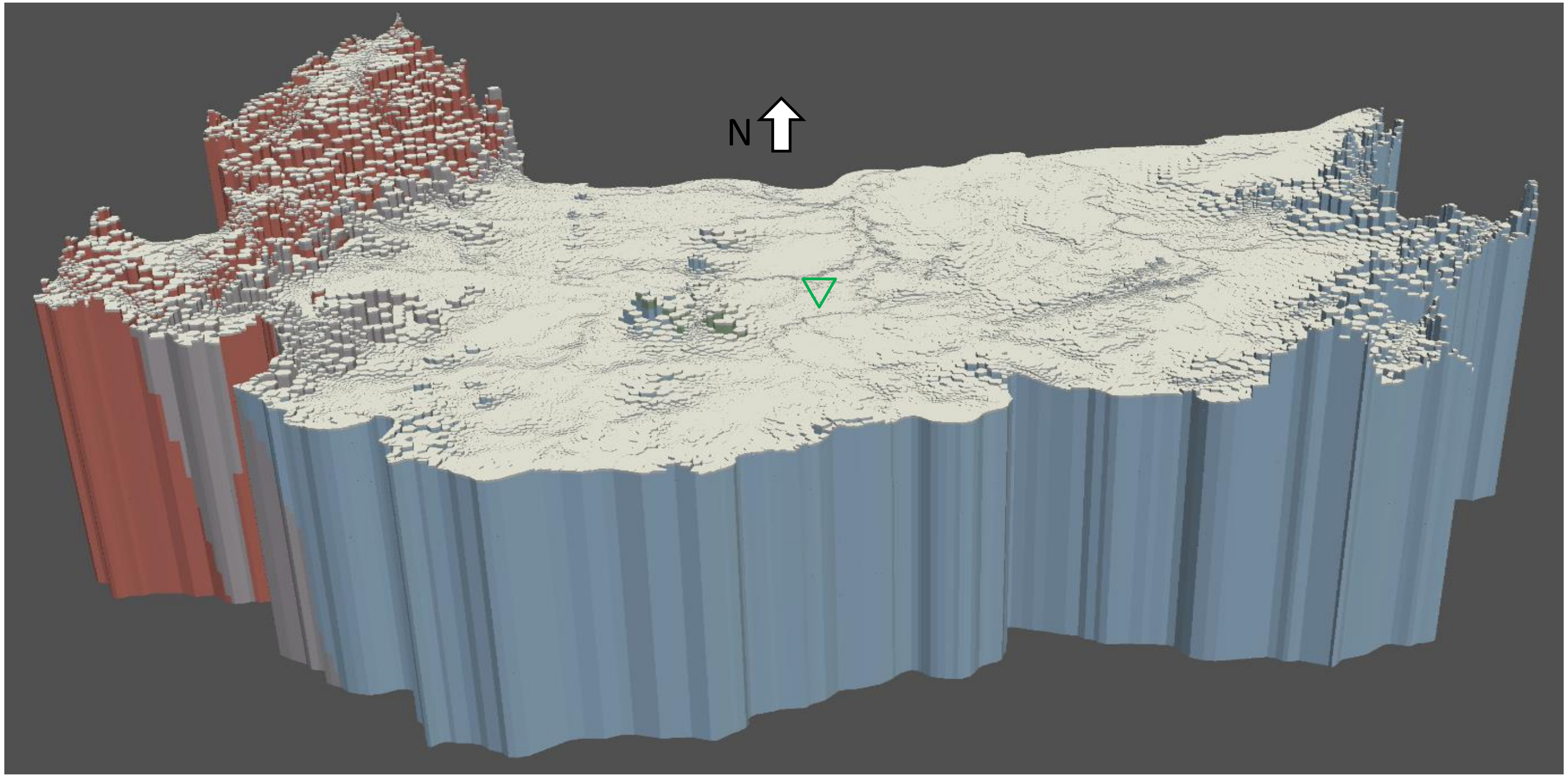
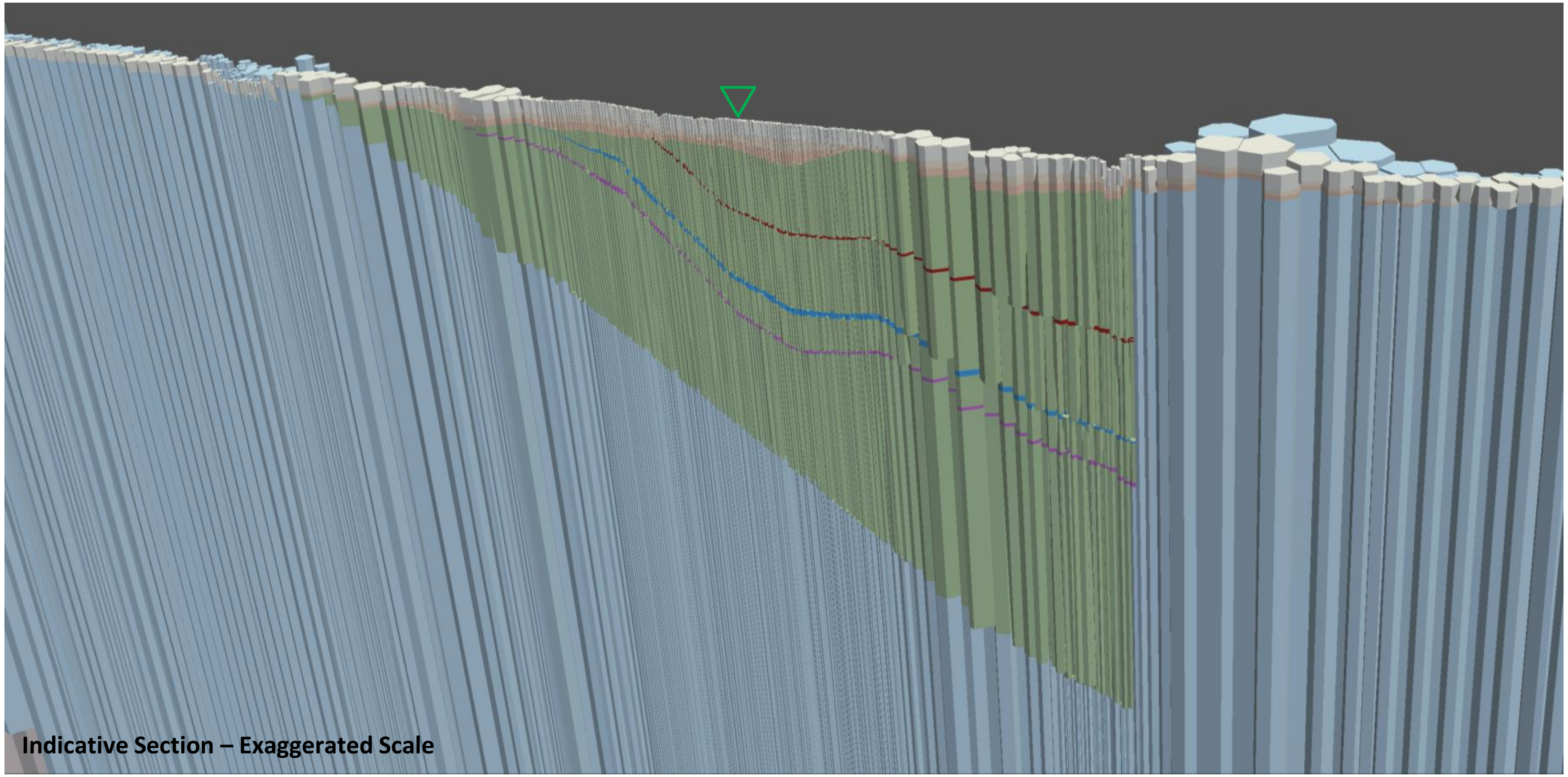


Fig. 1. Physiography of the St Lawrence Sheet area.

Numerical Groundwater Model

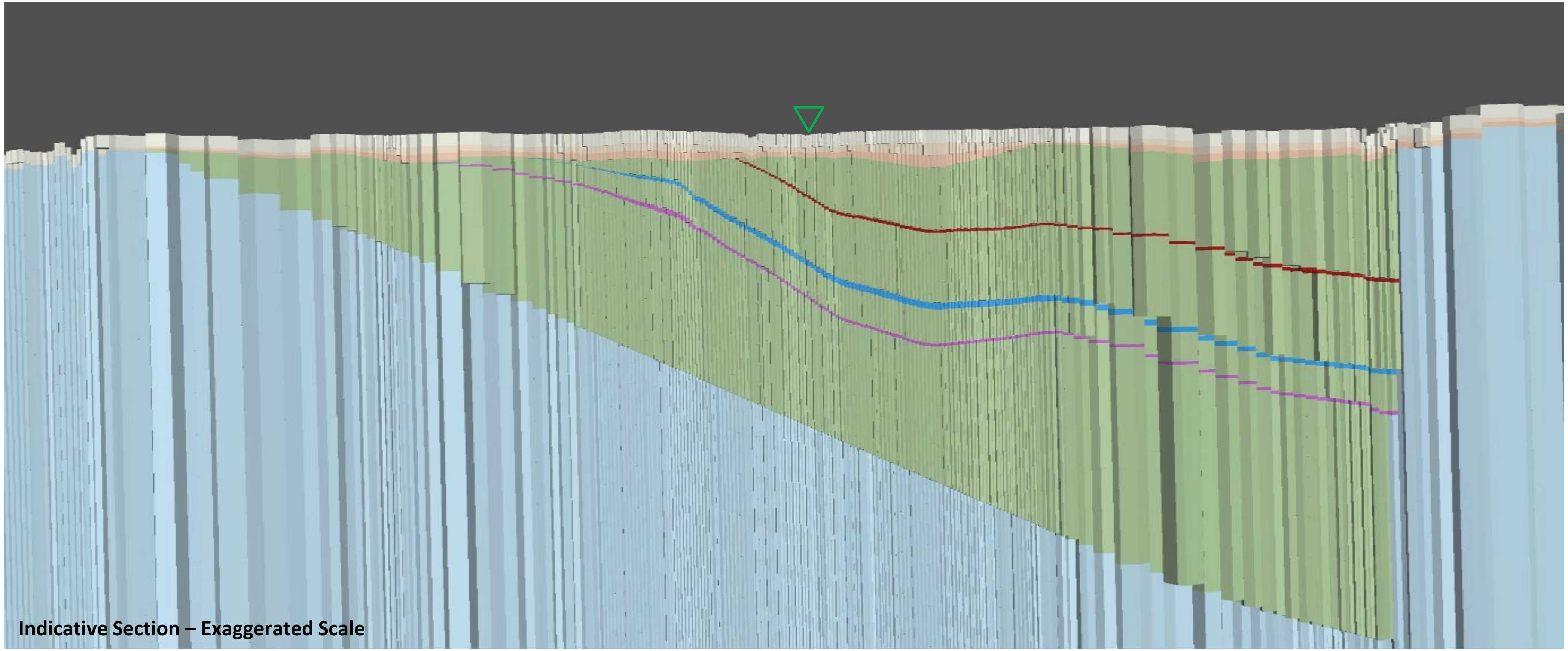


Numerical Groundwater Model



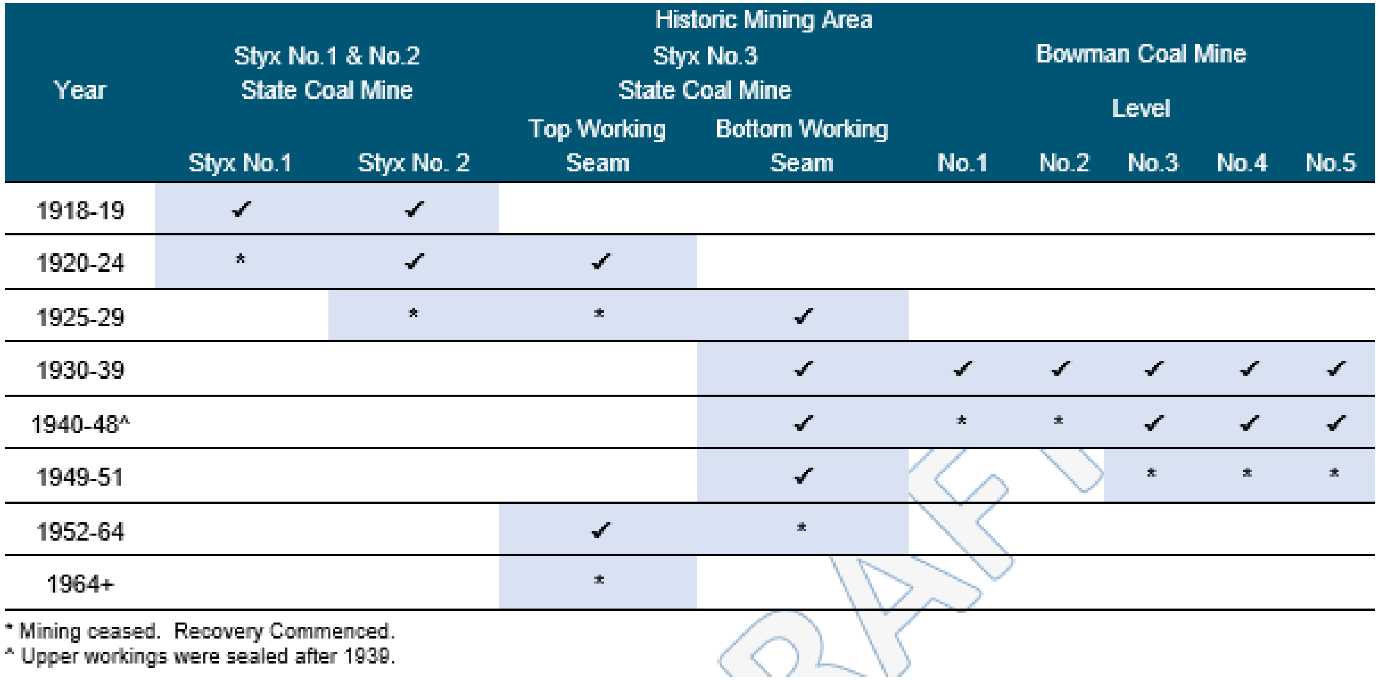
Indicative Section – Exaggerated Scale

Numerical Groundwater Model



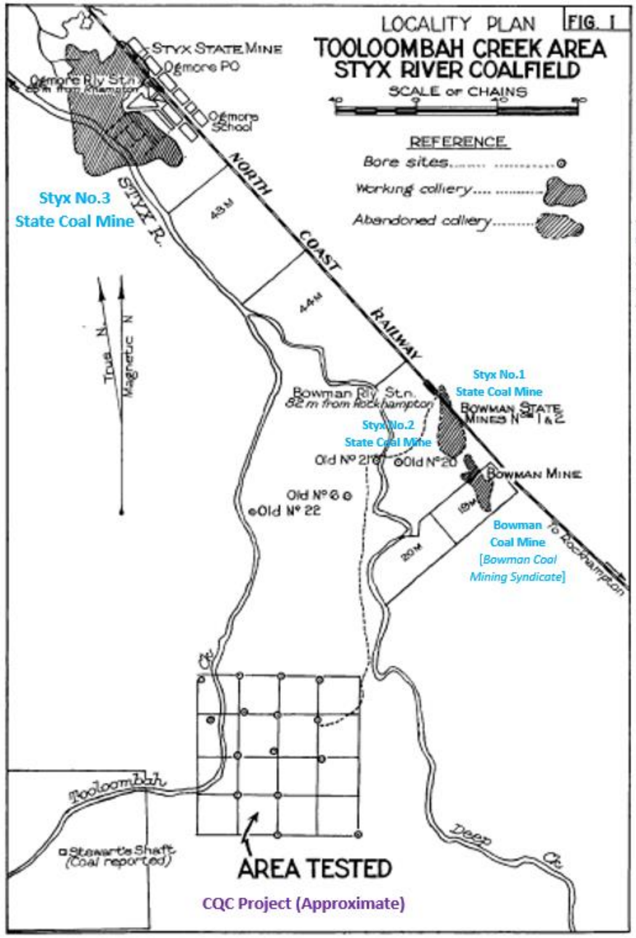
Numerical Groundwater Model

- Historical Review ✓

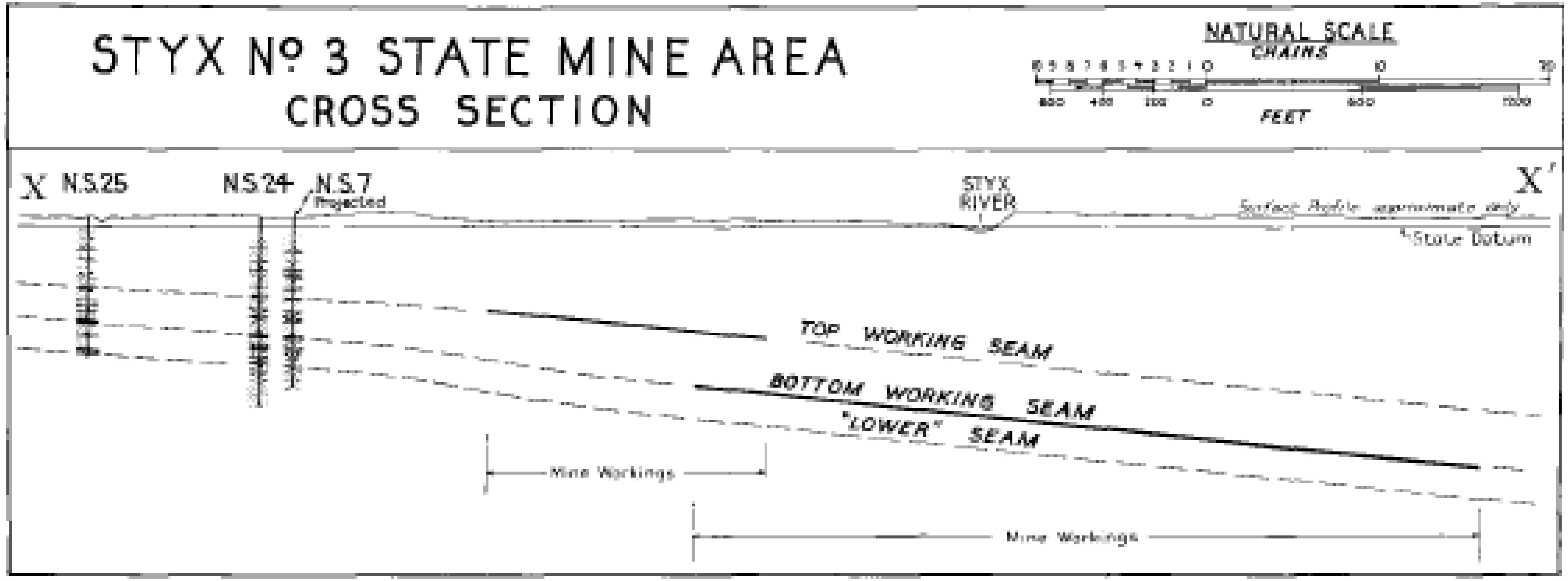


Year	Historic Mining Area Styx No.1 & No.2 State Coal Mine		Styx No.3 State Coal Mine		Bowman Coal Mine Level				
	Styx No.1	Styx No. 2	Top Working Seam	Bottom Working Seam	No.1	No.2	No.3	No.4	No.5
1918-19	✓	✓							
1920-24	*	✓	✓						
1925-29		*	*	✓					
1930-39				✓	✓	✓	✓	✓	✓
1940-48^				✓	*	*	✓	✓	✓
1949-51				✓			*	*	*
1952-64			✓	*					
1964+			*						

* Mining ceased. Recovery Commenced.
^ Upper workings were sealed after 1939.

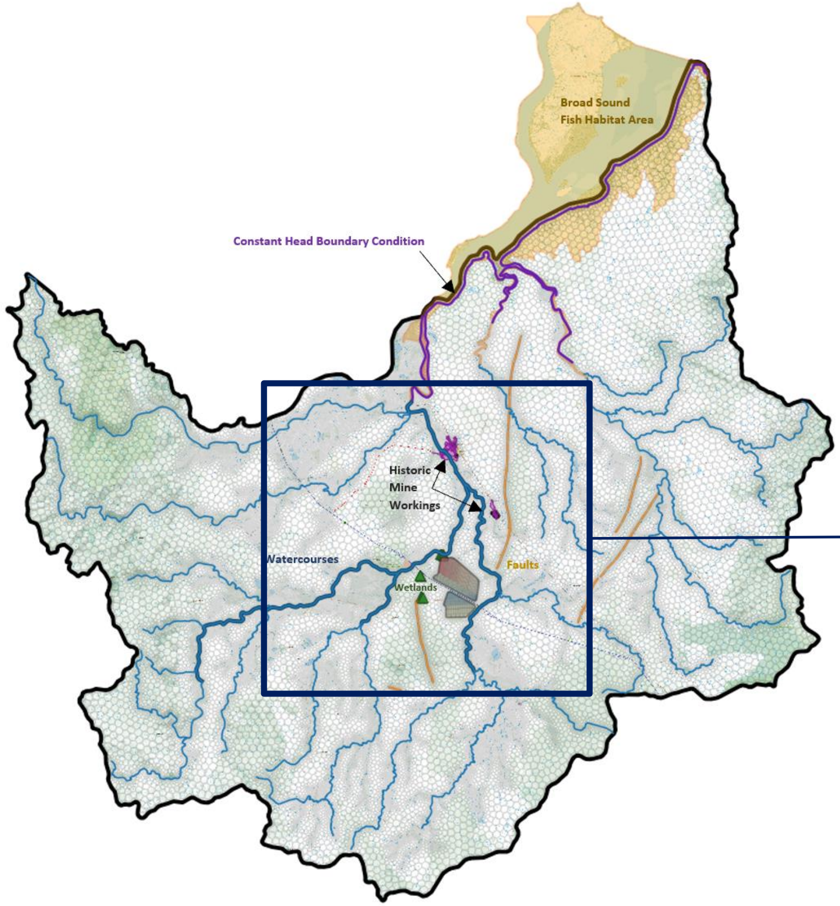


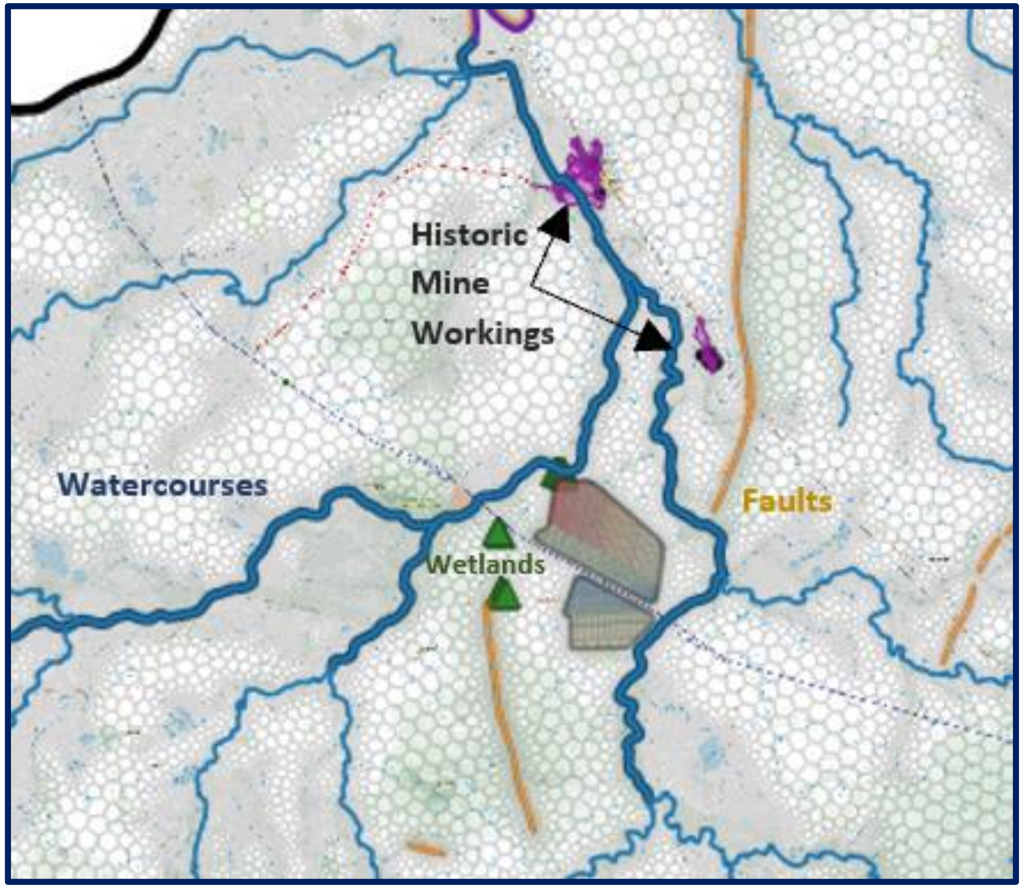
Numerical Groundwater Model



[*Source: Chong, 1964*]

Numerical Groundwater Model



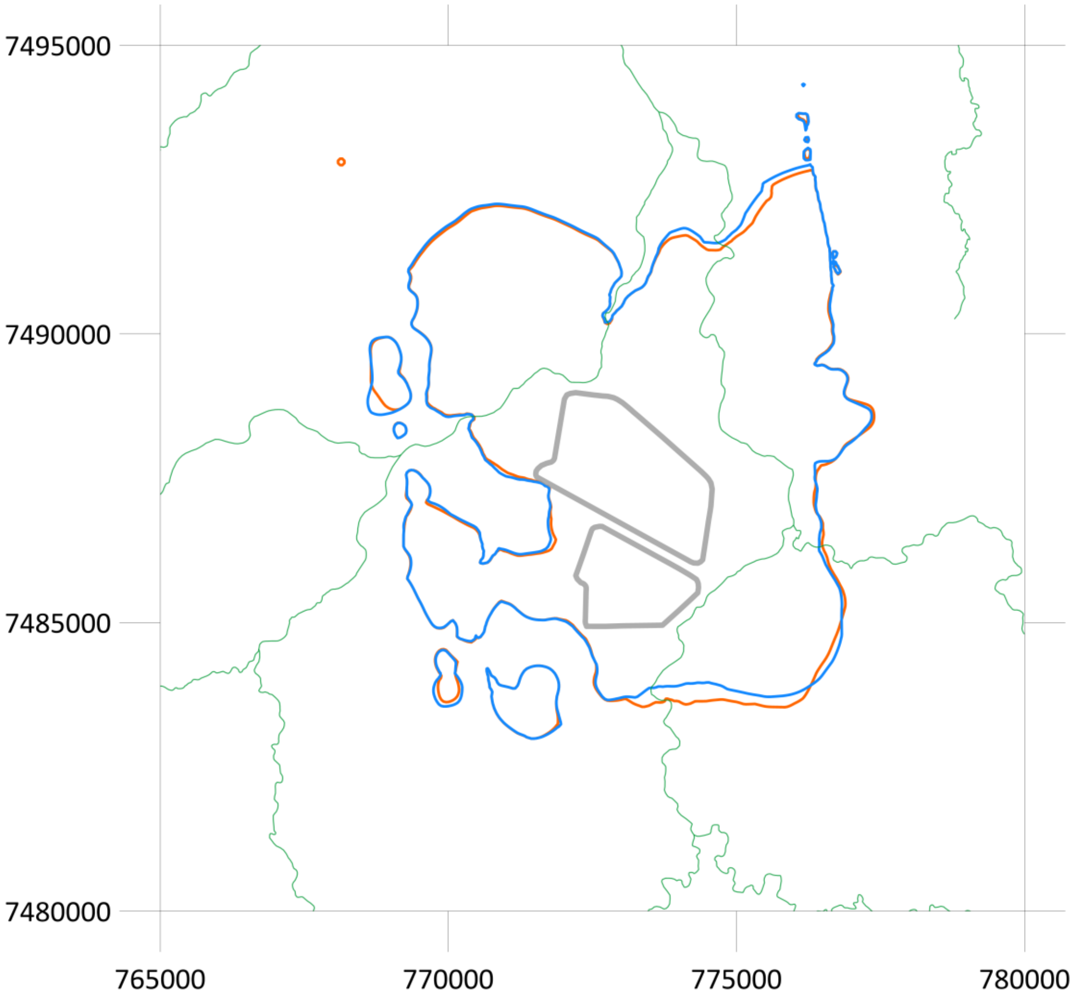


Model Improvement Progress

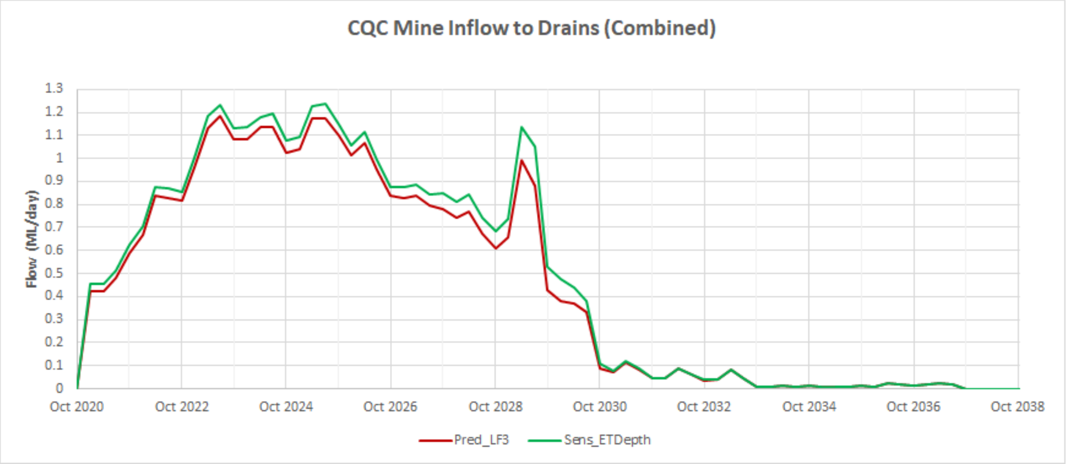
- Groundwater Inflow / Water Take Predictions → WRM
- Groundwater Drawdown Extents per Layer → Orange Environmental
- Potential Indirect Groundwater Drawdown Influence on Features → WRM / Eco Logical

Thank You

ATTACHMENT 18
ADDITIONAL PARAMETER ANALYSIS – KEY MODEL OUTPUTS

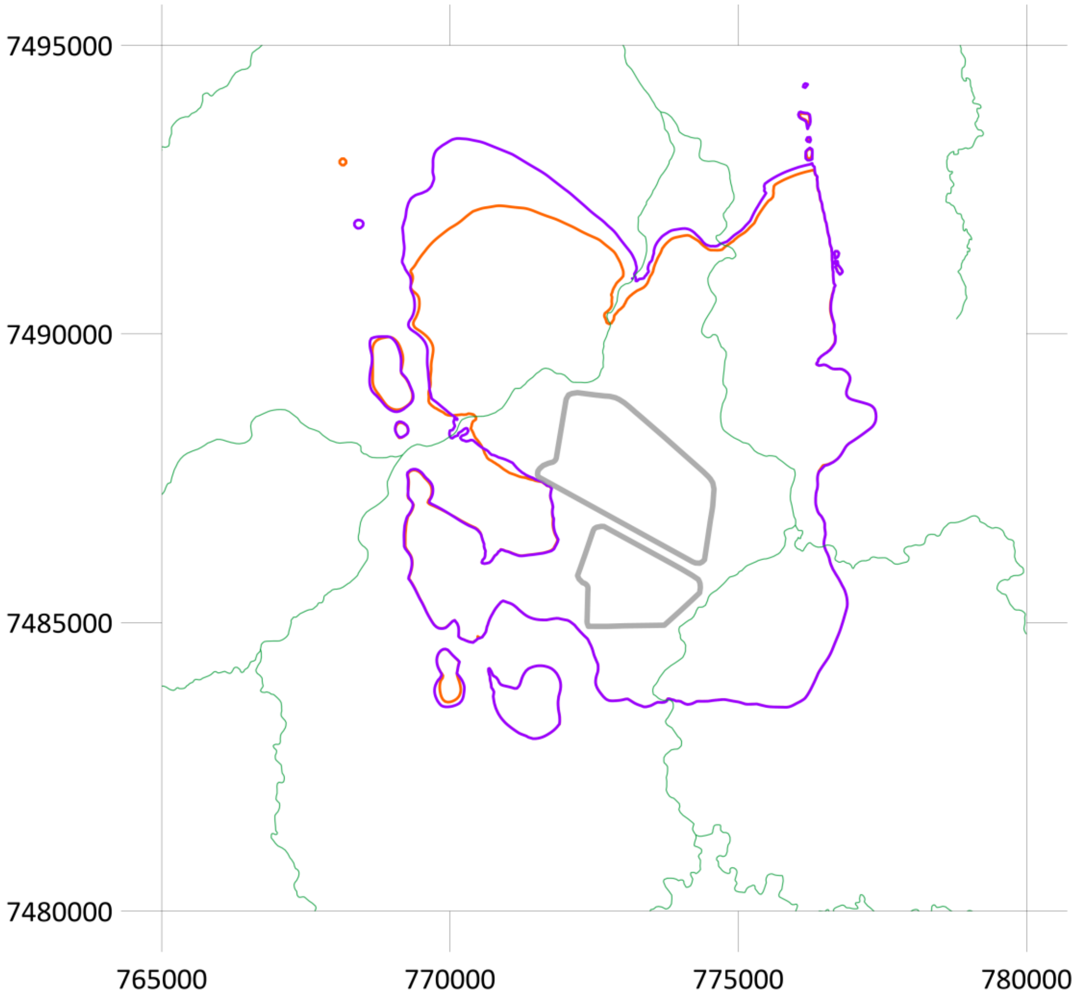


Layer 2 Maximum Predicted Drawdown (2 m Contour) Difference
[LF3 Model = Orange Line; Sensitivity = Blue Line]

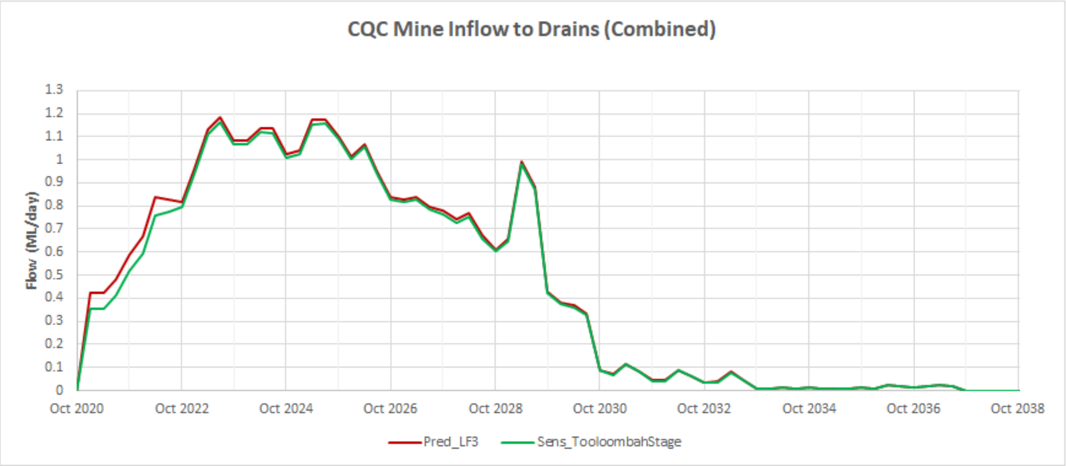


Predicted Mine Inflows (Drains, Both Pits Combined)
[LF3 Model = Red Line; Sensitivity = Green Line]

[X] Model Sensitivity Outputs with Reduced ET Extinction Depth

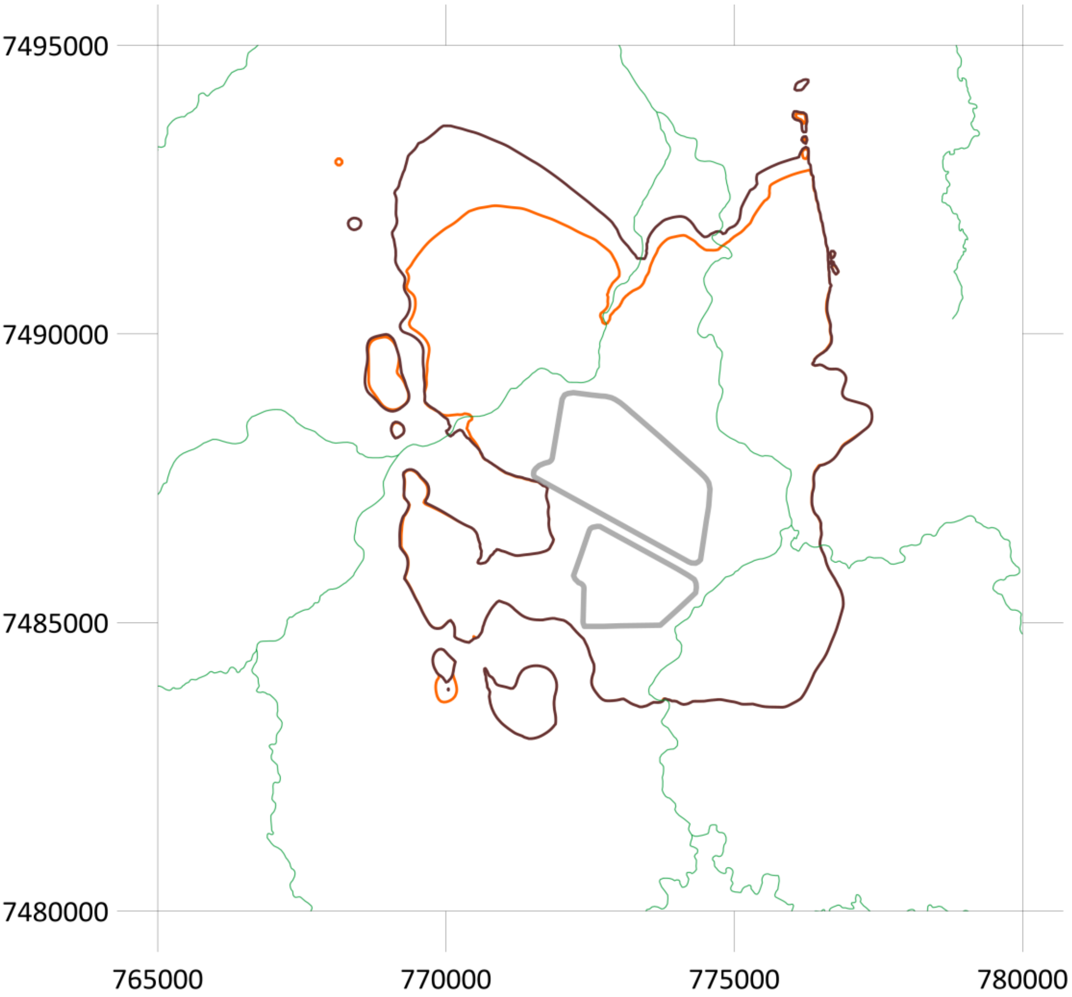


Layer 2 Maximum Predicted Drawdown (2 m Contour) Difference
[LF3 Model = Orange Line; Sensitivity = Purple Line]

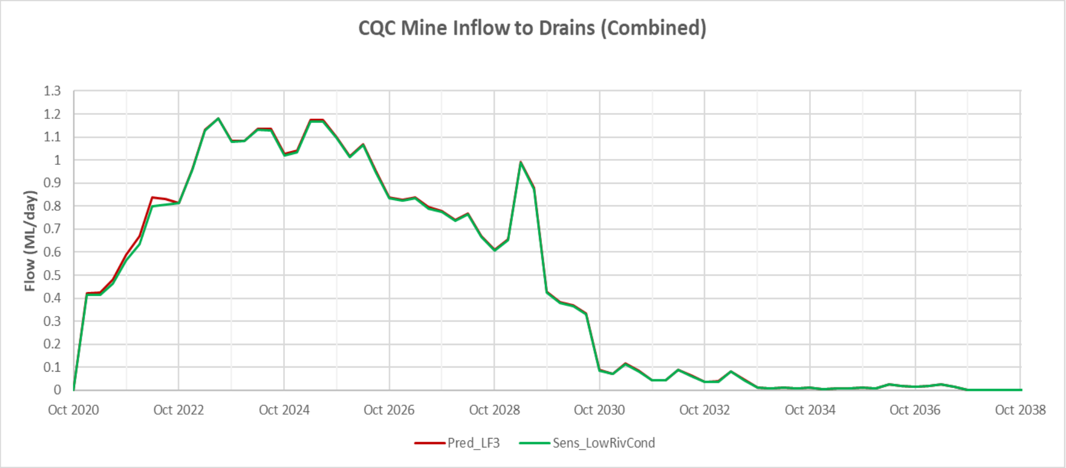


Predicted Mine Inflows (Drains, Both Pits Combined)
[LF3 Model = Red Line; Sensitivity = Green Line]

[XI] Model Sensitivity Outputs with Tooloombah Creek Boundary Condition Removed

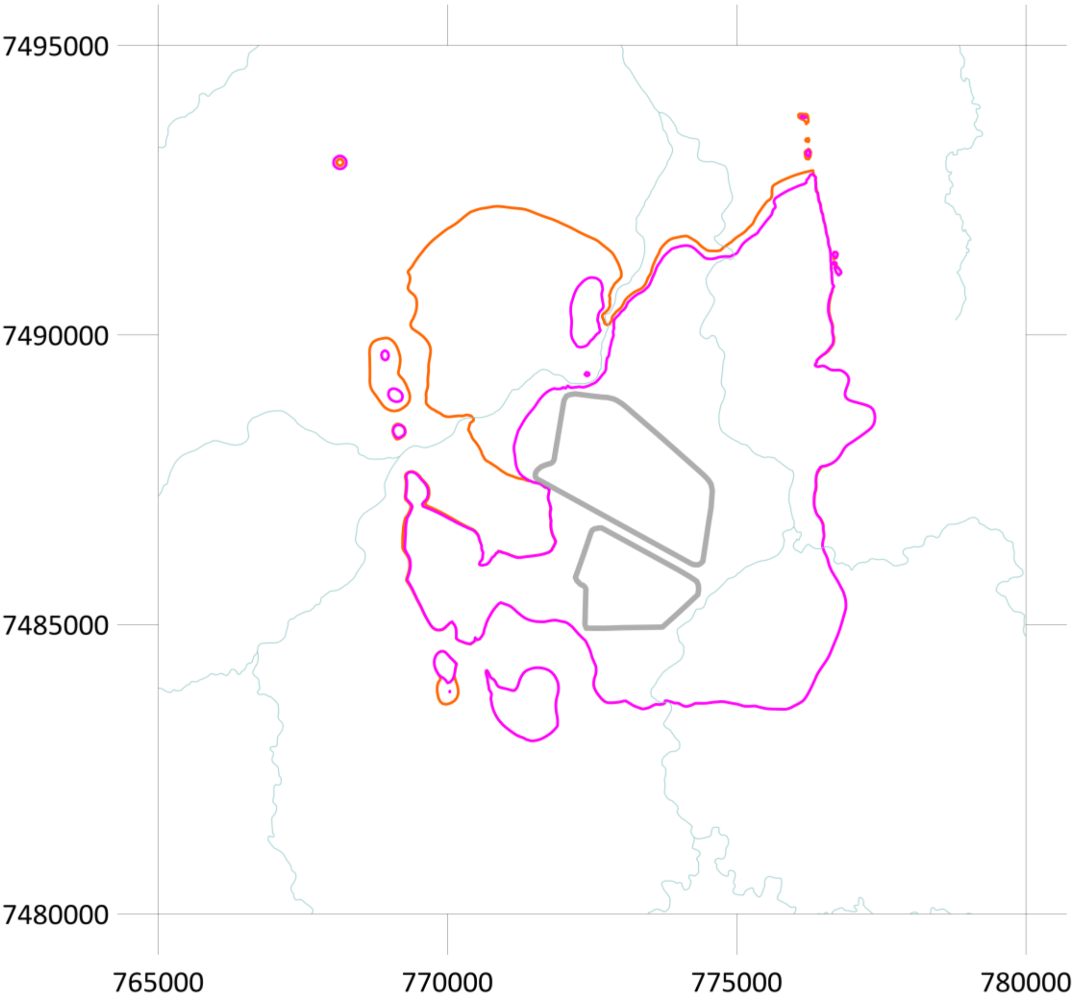


Layer 2 Maximum Predicted Drawdown (2 m Contour) Difference
[LF3 Model = Orange Line; Sensitivity (Lower K) = Brown Line]

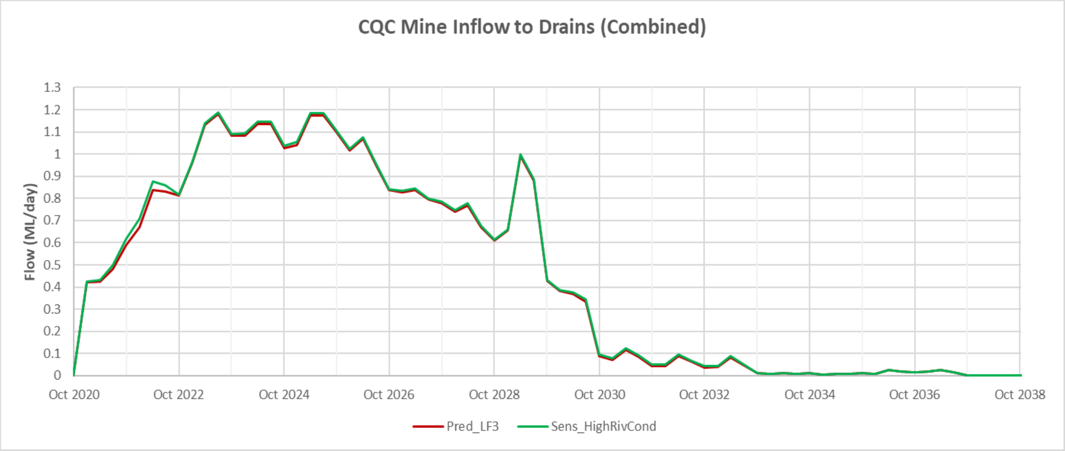


Predicted Mine Inflows (Drains, Both Pits Combined)
[LF3 Model = Red Line; Sensitivity (Lower K) = Green Line]

[XII] Model Sensitivity Outputs with Reduced River Bed Conductance



Layer 2 Maximum Predicted Drawdown (2 m Contour) Difference
[LF3 Model = Orange Line; Sensitivity (Higher K) = Pink Line]



Predicted Mine Inflows (Drains, Both Pits Combined)
[LF3 Model = Red Line; Sensitivity (Higher K) = Green Line]

[XII] Model Sensitivity Outputs with Enhanced River Bed Conductance

ATTACHMENT 19
ENDNOTES

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[i] https://www.business.qld.gov.au/industries/mining-energy-water/resources/environment-water/ogia
[Accessed 11 October 2019]

[ii] https://www.legislation.qld.gov.au/view/pdf/inforce/current/sl-2004-0240
[Accessed 6 August 2019]

[iii] http://elibrary.gbrmpa.gov.au/jspui/bitstream/11017/3474/10/Outlook-Report-2019-FINAL.pdf
[Accessed 10 February 2020]

[iv] http://www.bom.gov.au/climate/averages/climatology/evapotrans/text/evapotranspiration-paper.pdf
[Accessed 9 September 2019]

[v] https://environment.des.qld.gov.au/water/policy/pdf/draft-fitzroy-cap-coast-burdekin-haughton-don-groundwater-report-2018.pdf
[Accessed 6 August 2019]

[vi] http://www.livingstone.qld.gov.au/1565/Water-Treatment-and-Supply
[Accessed 22 October 2019]

[vii] CQC-SCP_Data.accdb
[Accessed 7 January 2020] {*Includes confidence filters as provided by Orange Environmental*}

[viii] http://www.bom.gov.au/ntc/IDO59001/IDO59001_2019_QLD_TP082.pdf
[Accessed 29 November 2019]

[ix] http://www.bom.gov.au/water/groundwater/explorer/map.shtml
[Accessed 1 November 2019]

[x] https://www.defence.gov.au/id/_Master/docs/NCRP/QLD/0219ShoalwaterBayTrainingAreaQLD.pdf
[Accessed
27 November 2019]

[xi] https://www.environment.gov.au/water/wetlands/australian-wetlands-database/directory-important-wetlands
[Accessed 6 August 2019]

[xii] https://www.legislation.qld.gov.au/view/pdf/inforce/current/sl-2004-0240
[Accessed 6 August 2019]

[xiii] http://www.ga.gov.au/scientific-topics/energy/province-sedimentary-basin-geology/petroleum/onshore-australia/styx-basin
[Accessed 12 November 2019]

[xiv] https://www.bioregionalassessments.gov.au/assessments/15-current-water-accounts-and-water-quality-hunter-subregion/15222-salinity
[Accessed 16 January 2020]

[xv] 20190337 A Fulton STX Boreholes Preliminary Data.xlsx
[Accessed 14 November 2019]

[xvi] https://www.algocompute.com/
[Accessed 27 March 2020]

[xvii] http://www.pesthomepage.org/Home.php
[Accessed 17 February 2020]

[xviii] https://environment.des.qld.gov.au/__data/assets/pdf_file/0036/88398/rs-gl-uwir-final-report.pdf
[Accessed 12 February 2020]

[xix] https://www.climatechangeinaustralia.gov.au/en
[Accessed 5 December 2019]

[xx] https://www.qld.gov.au/environment/coasts-waterways/plans/hazards/sea-level-mapping
[Accessed 20 January 2020]

[xxi] https://www.qld.gov.au/__data/assets/word_doc/0037/87949/tor-guideline-water.docx
[Accessed 14 October 2019]

[xxii] GW Results Summary Table 200312.xlsx
[Accessed 13 March 2020]