

Date : 6/01/2023 5:43:27 PM

From : "ESR"

To : "Jamie Merrick" Jamie.Merrick@des.qld.gov.au, "Alena Tracey" Alena.Tracey@des.qld.gov.au, "DLO DES"

DLO.DES@des.qld.gov.au, "Peter Tones" Peter.Tones@des.qld.gov.au, "Media DES" Media@des.qld.gov.au

Cc : "ESR" ESR@des.qld.gov.au, "ESR Snr Mgt" ESRsNrMgt@des.qld.gov.au, "Rob Lawrence" Rob.Lawrence@des.qld.gov.au,

"Alicia Kennedy" Alicia.Kennedy@des.qld.gov.au, "Corro DES ESR CCC" DESESRCCC.Corro@des.qld.gov.au

Subject : 22-030 ESR Alert Update: Engagement of CSIRO and GA to undertake review of groundwater reports for Carmichael Coal Mine

Attachment : image001.png;image002.png;

Good afternoon,

Please see update to the alert below.

For MO Information

- On 28 December 2022, Bravus wrote to DES providing details of progress of the groundwater model review.
- Bravus has indicated that the groundwater reports will not be completed by 10 January 2023 as required by the EA due to the availability of technical specialists and its peer reviewer. However the company will be providing DES with a presentation on the groundwater model results on 10 January 2023.
- The company has indicated that the reports will be provided to DES by 31 January 2023.
- Officers have considered the delay in the submission of the review, and at this point are not intending to take any compliance action. A short delay is not unreasonable to ensure that the reports are robust and peer reviewed.
- DES has confirmed with CSIRO and Geoscience Australia that their review can commence once the groundwater reports are received.
- The reports are public register documents which are likely to be the subject of a request for release.

Kind regards,



Lindsay Hope (she/her)
Senior Program Officer
Office of the Deputy Director-General
Environmental Services and Regulation
Department of Environment and Science

P 07 3330 5535
E lindsay.hope@des.qld.gov.au
GPO Box 2454 Brisbane QLD 4001

From: ESR <ESR@des.qld.gov.au>

Sent: Friday, 9 December 2022 9:35 AM

To: Jamie Merrick; Alena Tracey; Allison Bambrick; DLO DES; Peter Tones; Media DES

Cc: ESR; ESR Snr Mgt; Rob Lawrence; Alicia Kennedy; Corro DES ESR CCC

Subject: 22-030 ESR Alert: Engagement of CSIRO and Geoscience Australia to undertake review of groundwater reports for Carmichael Coal Mine

For MO Information

ALERT NAME:

- Engagement of CSIRO and Geoscience Australia (GA) to undertake review of the Carmichael Coal Mine Groundwater Model Review Report (model report) and Final Groundwater Management and Monitoring Program (GMMP) Review Report.

CUSTOMER DETAILS & LOCATION:

- Bravus Resources & Mining (Environmental Authority (EA) holder Adani Mining Pty Ltd)
- Carmichael Coal Mine

ISSUE/S – (What happened?):

- As required by the EA, Bravus are required to undertake a review of the numerical groundwater model to incorporate groundwater monitoring data and measured mine dewatering volumes from its Groundwater Management and Monitoring Program.
- The review must provide a review of the hydrogeological conceptualisation used in the previous model, a revised numerical groundwater model that must include but is not limited to an update of the predicted impacts, a revised water balance model, predictions of changes in groundwater levels for a range of scenarios and an evaluation of the accuracy of the predicted changes.
- A Groundwater Model Review Report outlining the findings and any recommendations from the review is due to be submitted to the Department of Environment and Science (DES) by **10 January 2023**.
- Bravus must also provide the Final Groundwater Management and Monitoring Program Review Report by **10 January 2023**.
- DES has engaged CSIRO and GA to independently review the model report and Final GMMP Review Report.
- The CSIRO and GA review will provide a rigorous third-party scientific review of the revised model outcomes.

Eg is it acceptable to have a mining plan that results in 85% of the uncertainty analysis realisations predicting drawdown of less than 0.2 m at the springs.

A.Bleakley

Published on DETSI Disclosure Log
RTI Act 2009

Date : 12/01/2023 1:44:40 PM

From : "Shawn Michelmore"

To : "Kate Bennink" Kate.Bennink@des.qld.gov.au, "Juliana Mccosker" Juliana.Mccosker@des.qld.gov.au

Subject : FW: 22-030 ESR Alert Update: Engagement of CSIRO and GA to undertake review of groundwater reports for Carmichael Coal Mine

Attachment : image001.png;image003.png;

FYI

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BRAVUS

MINING & RESOURCES

Carmichael Coal Mine Project

Groundwater Model Review - Progress Meeting - 4

Tuesday 10 January 2023

BRAVUS

MINING & RESOURCES

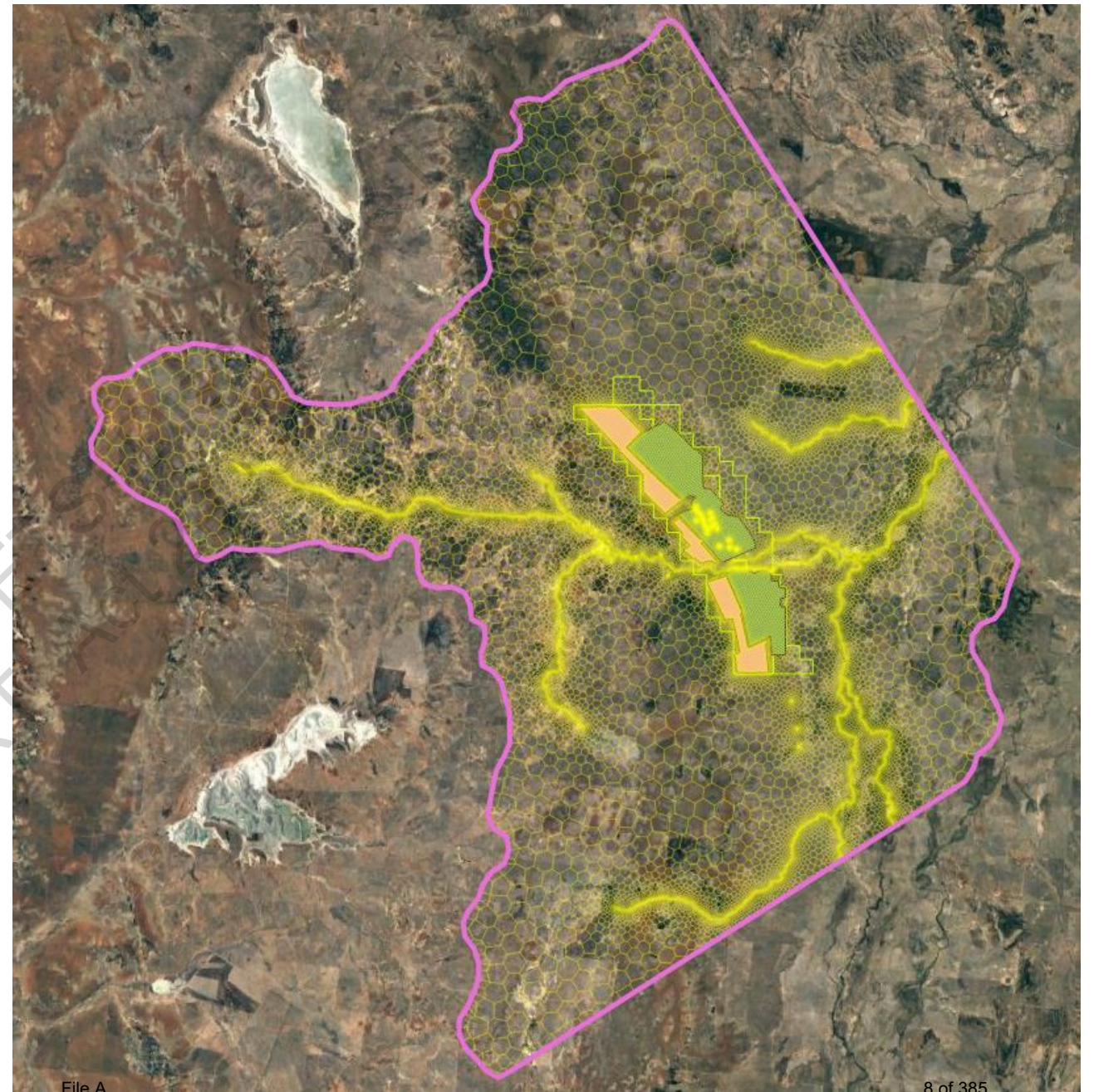
Model design information

Model design overview

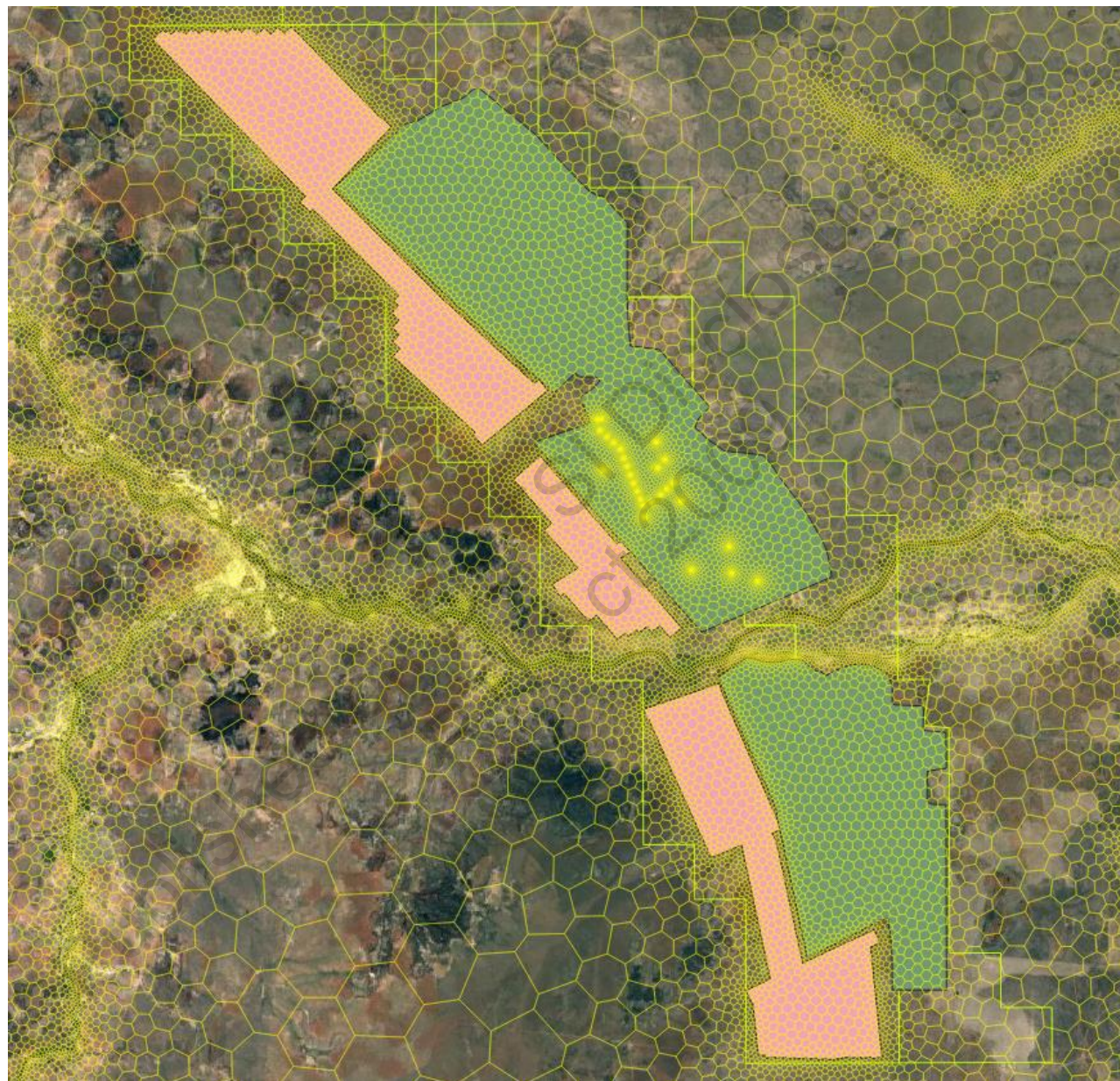
- MODFLOW-USG Transport v1.10
- Maintain domain from SEIS groundwater model
- Unstructured Voronoi polygon mesh; 34,624 nodes per layer
 - Refinement for major creeks, mapped springs, open cut and underground mine area, and dewatering bores
- 14 HSUs, one per model layer, with Rewan Formation split across two model layers
- Model layers developed based on further work by Titus Murray, extrapolated to merge with Bioregional Assessment HSU layers towards edges of the model domain
- Model layers pinched out where HSU conceptualised to not exist
 - 519,360 total nodes; 233,967 active nodes
- Regional head boundary conditions based on Bioregional Assessment head contours
- Major watercourses simulated with flow in wet season only; behave as drains otherwise
- Springs simulated by drain boundary conditions in source aquifer (DSC = Clematis, Mellaluka = Joe Joe), with drain return to alluvium at DSC
- Recharge defined as a percentage of measured rainfall, variable per outcropping HSU
- Potential evapotranspiration constant across model domain, with enhanced extinction depth for deeper-rooted vegetation aligned with riverine corridors
- Transient history-matching employs quarterly stress periods prior to mining activities; monthly thereafter
- Predictions employ seasonal stress periods, incorporating mine dewatering and hydraulic conductivity enhancement associated with fracturing above longwall panels

Mesh

- Variable node spacing variable in line with stresses, monitoring and areas of interest with regard to the modelling objectives:
 - production bores: 20 m;
 - open cut mining: 500 m;
 - underground mining: 500 m;
 - buffer zone around underground mining to account for horizontal stress relief: 200 m;
 - major creeks: 150 m;
 - Doongmabulla Springs: 200 m; and
 - other mapped springs: 100 m



Mesh



Model layers

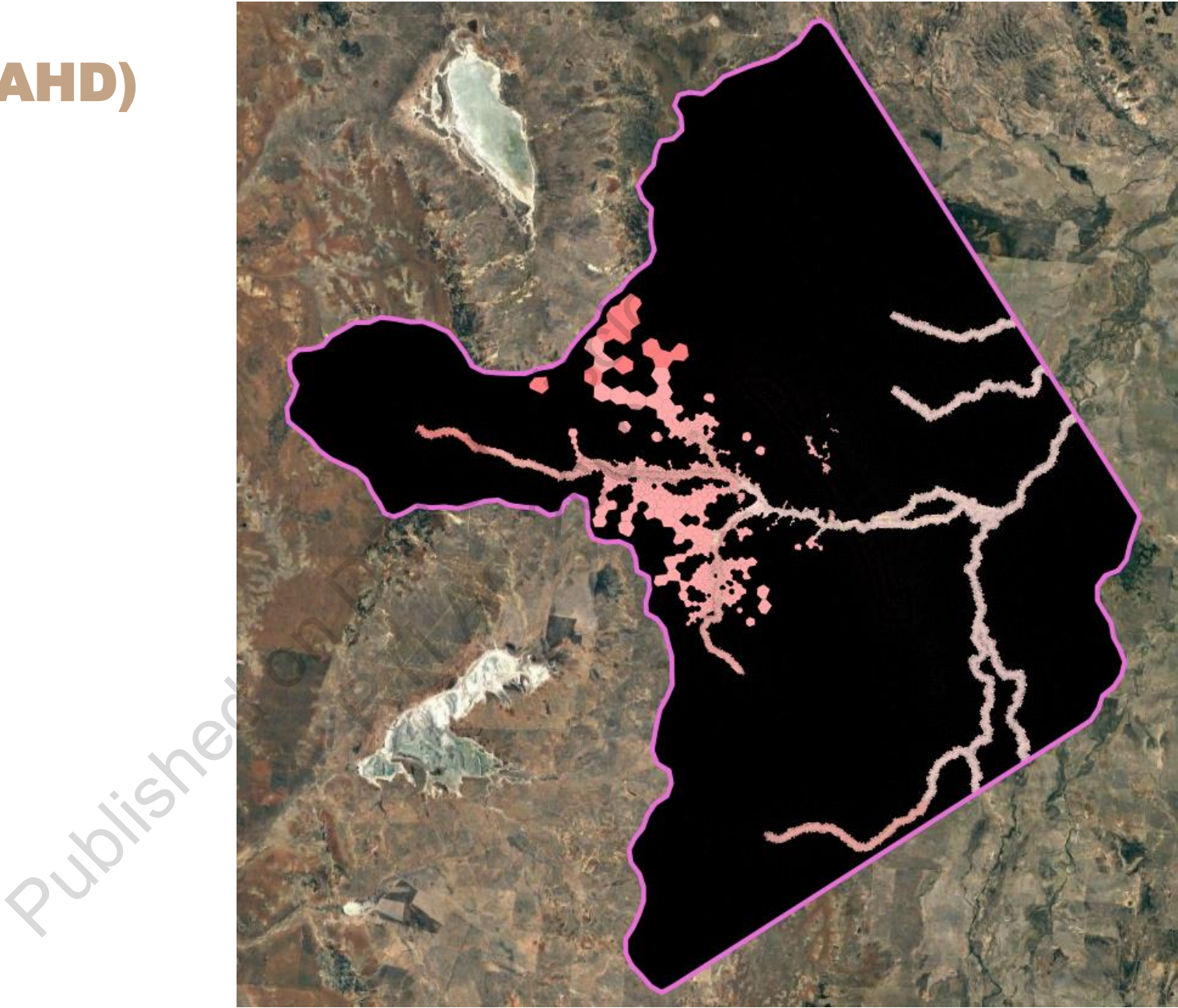
Model layer	HSU
1	Quaternary alluvium
2	Weathering zone
3	Tertiary and non-alluvial Quaternary deposits
4	Moolayember Formation
5	Clematis Sandstone / Warang Sandstone
6	Dunda Beds
7	Rewan Formation (upper)
8	Rewan Formation (lower)
9	Bandanna Formation
10	Bandanna Formation (AB Seam coal)
11	Bandanna Formation
12	Colinlea Sandstone
13	Colinlea Sandstone (D Seam coal)
14	Colinlea Sandstone
15	Joe Joe Group

22-312

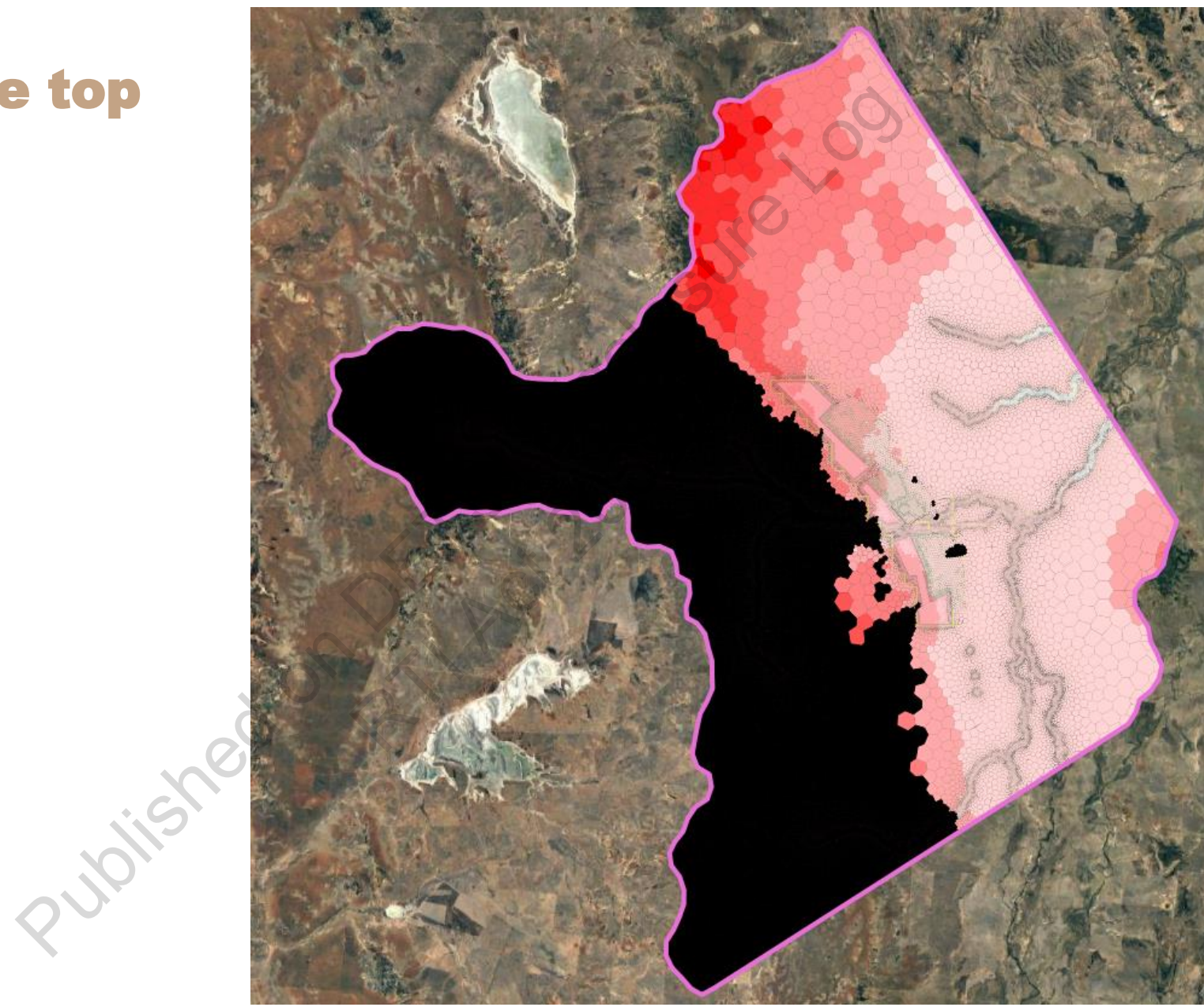
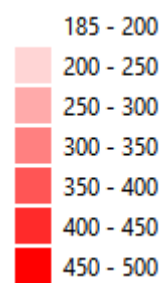
File A

10 of 385

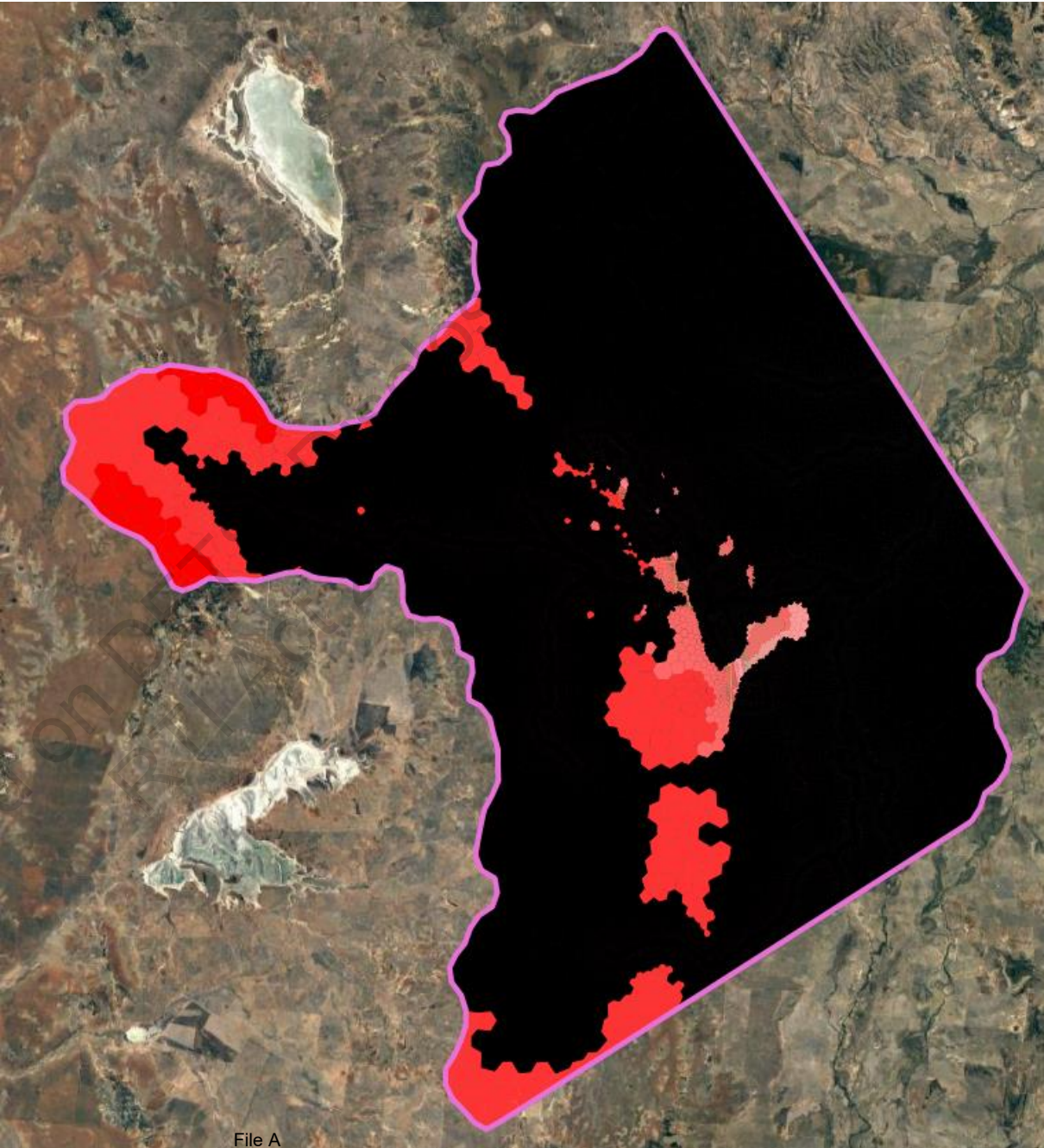
Alluvium top (mAHD)



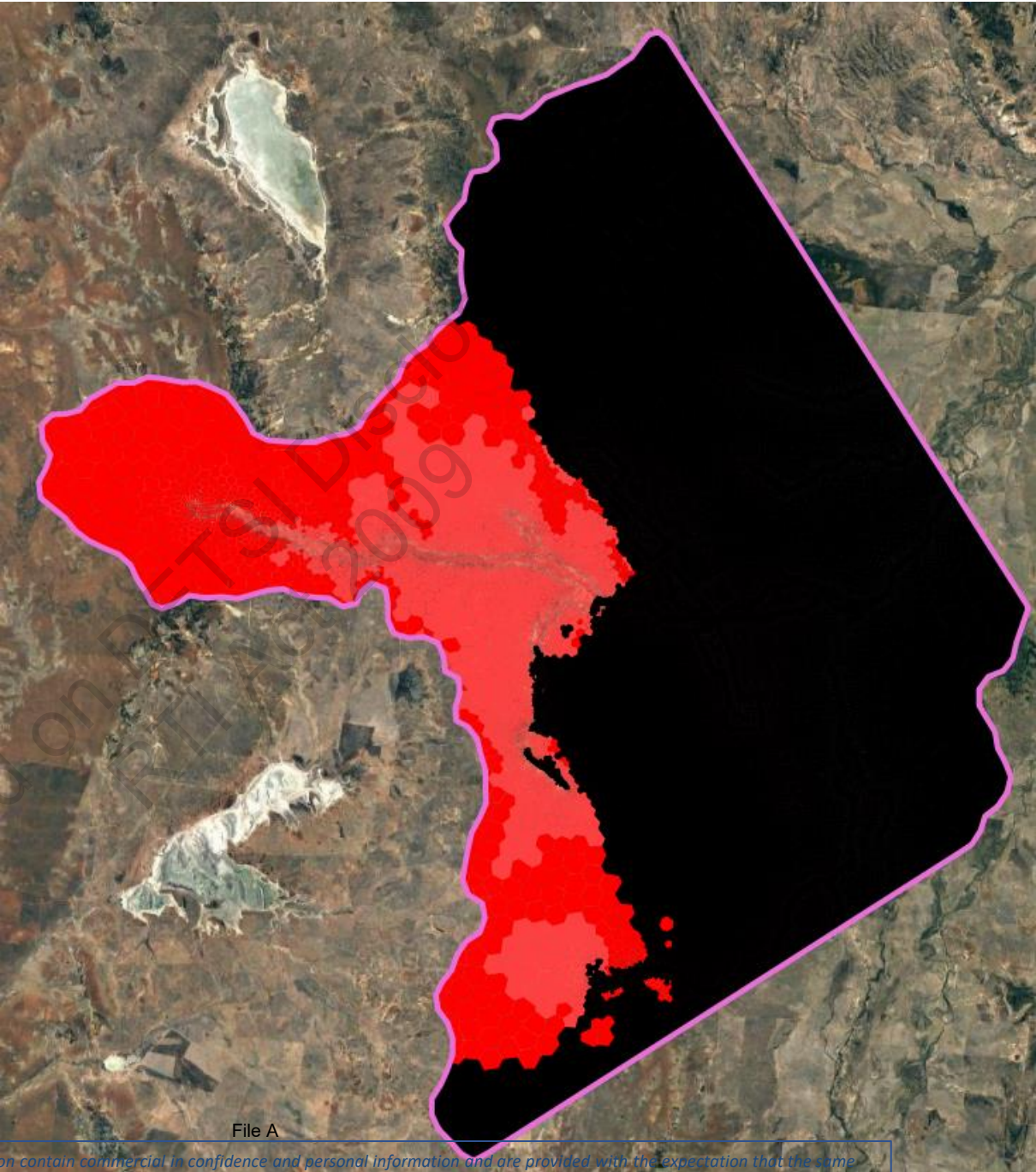
Weathering zone top (mAHD)



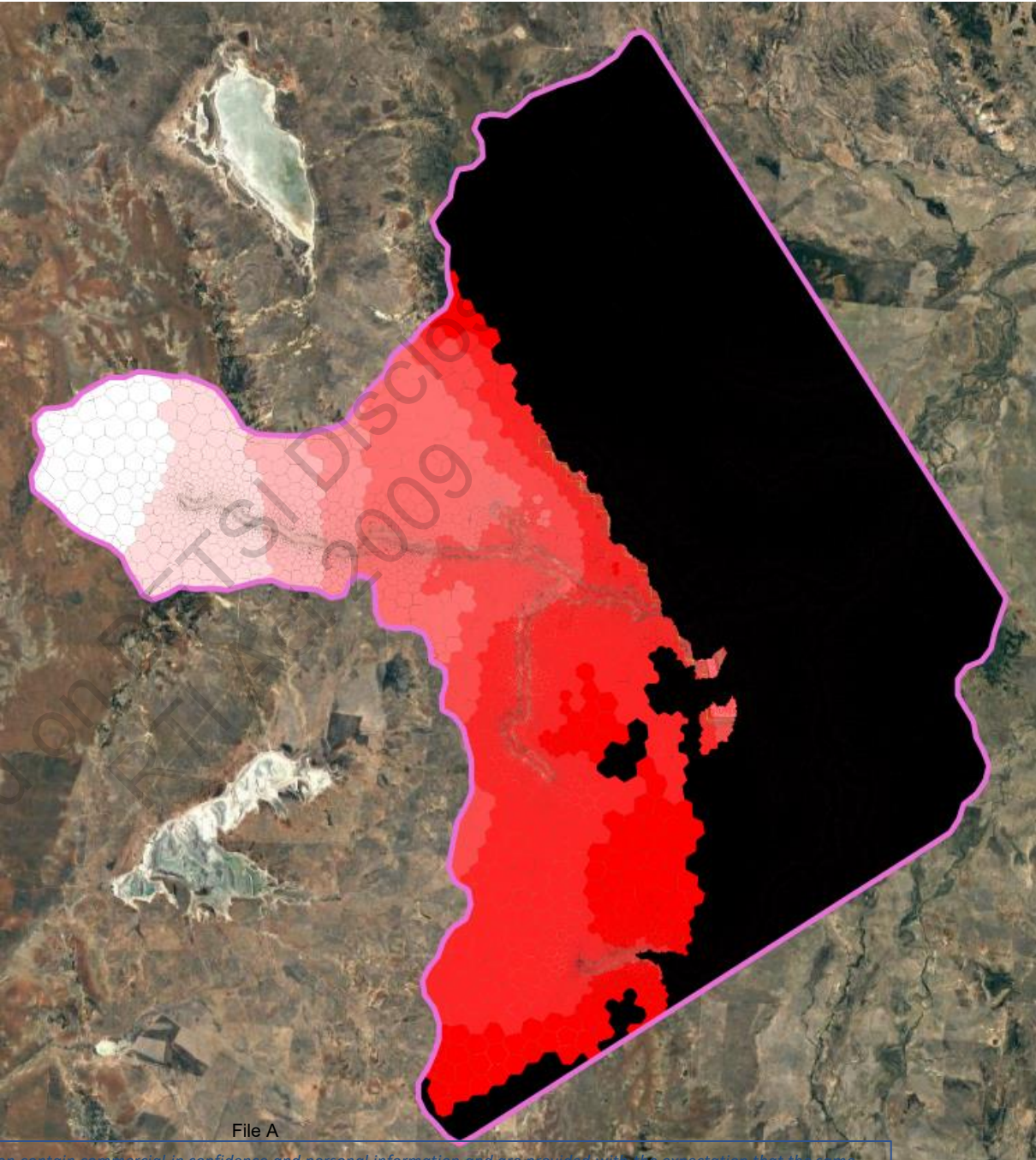
Tertiary top (mAHD)



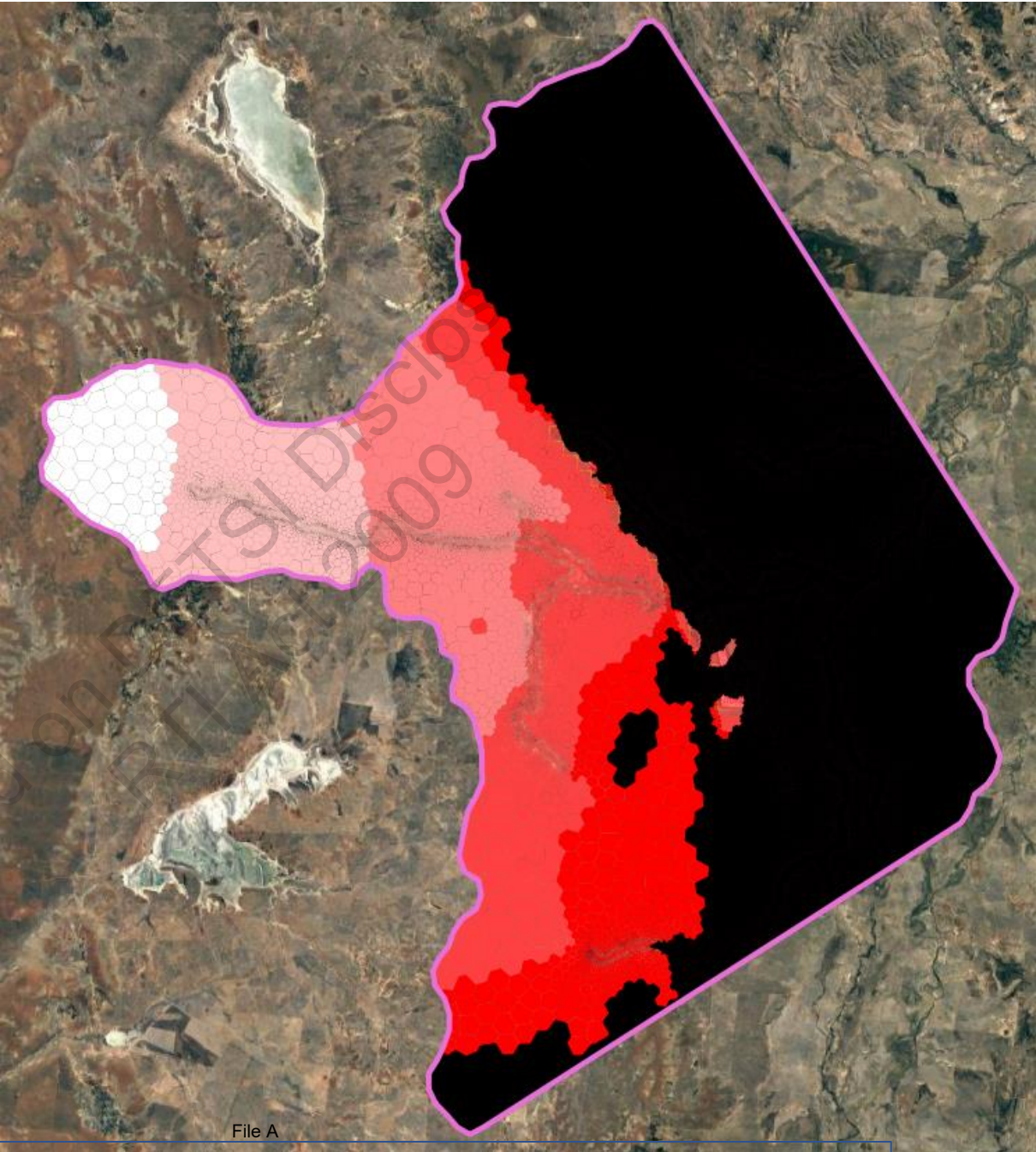
Moolayember top (mAHD)



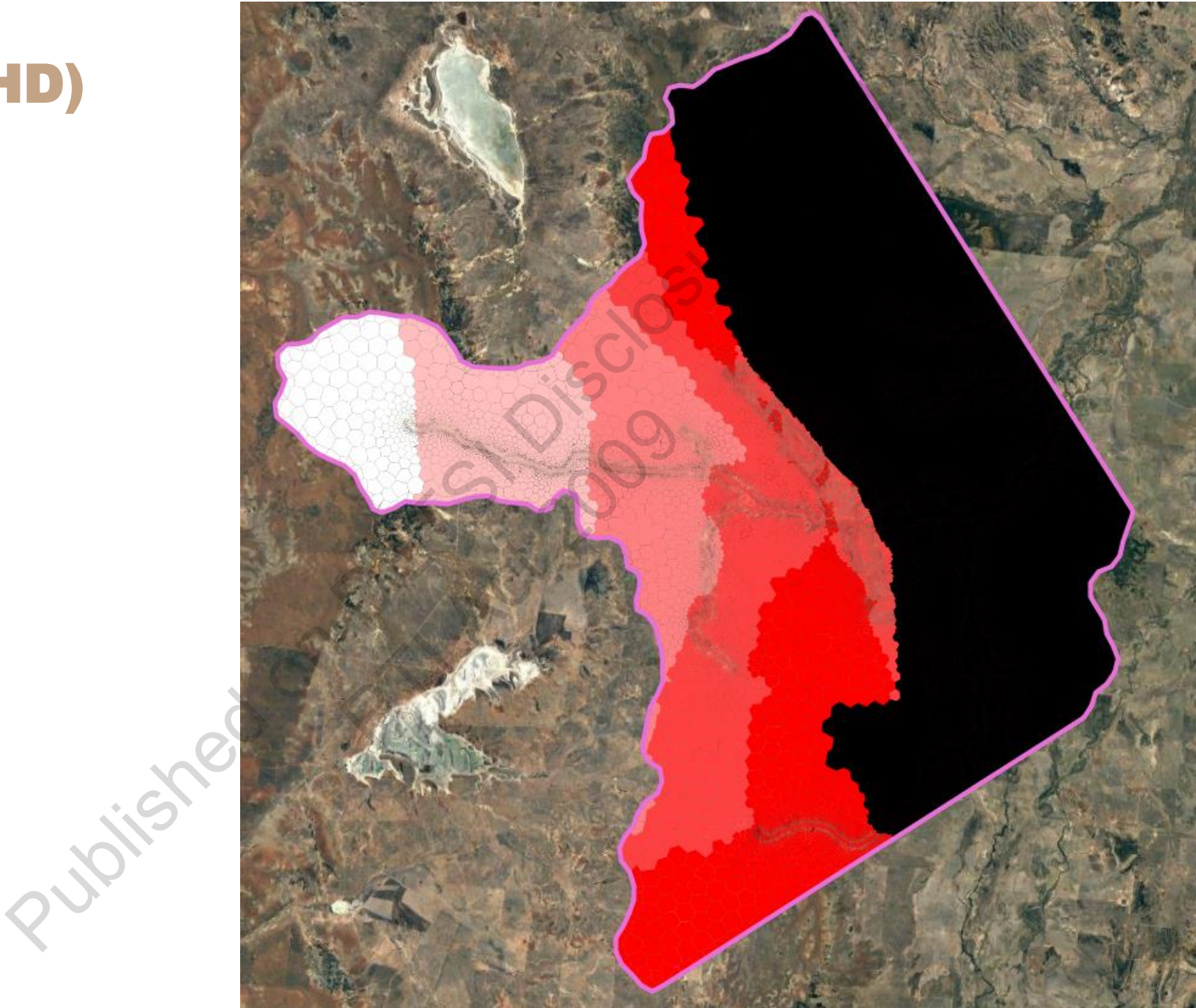
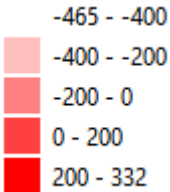
Clematis top (mAHD)



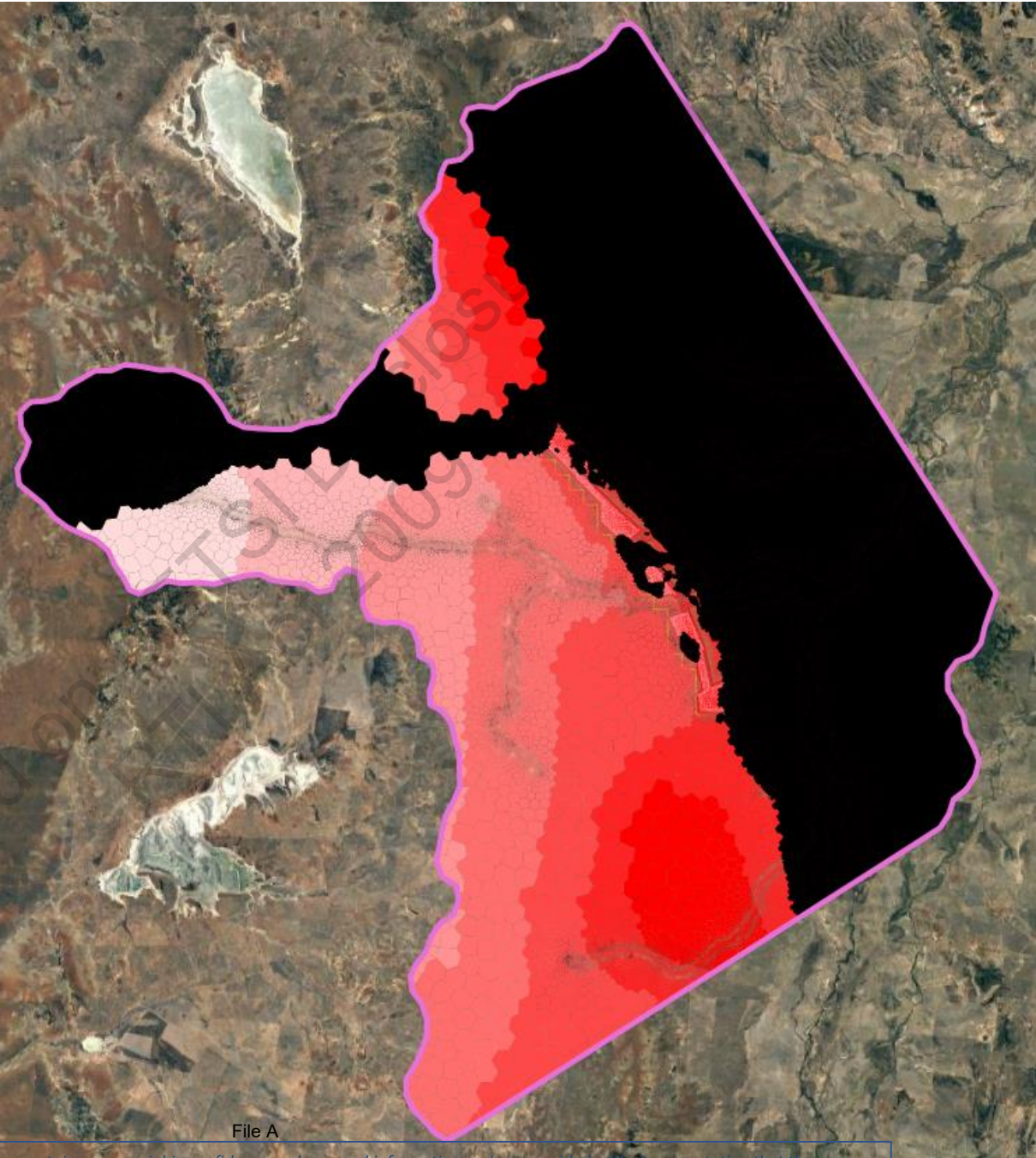
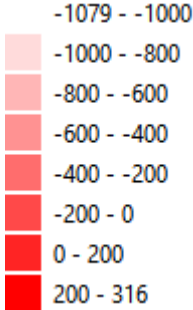
Dunda top (mAHD)



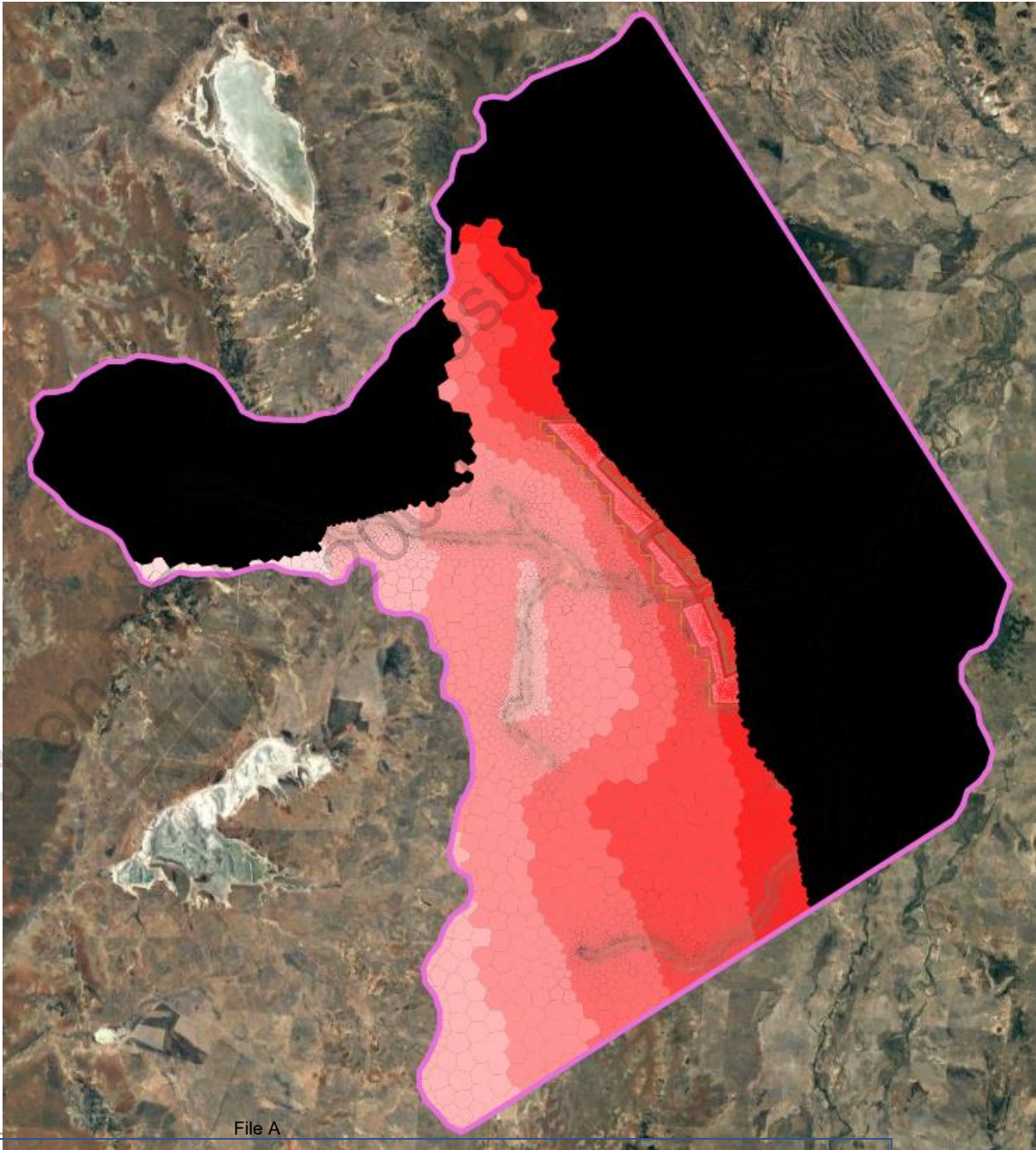
Rewan top (mAHD)



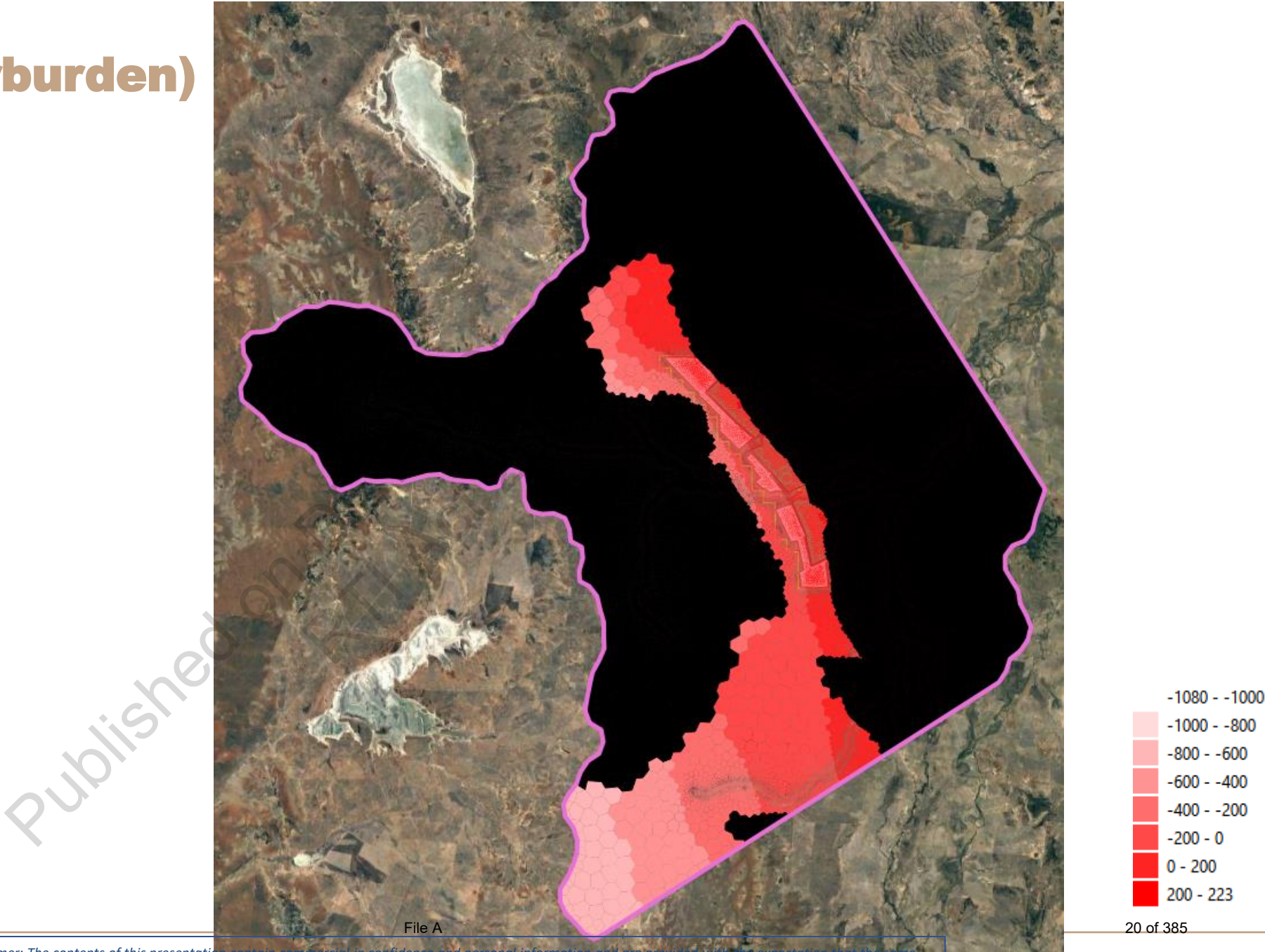
Bandanna top (mAHD)



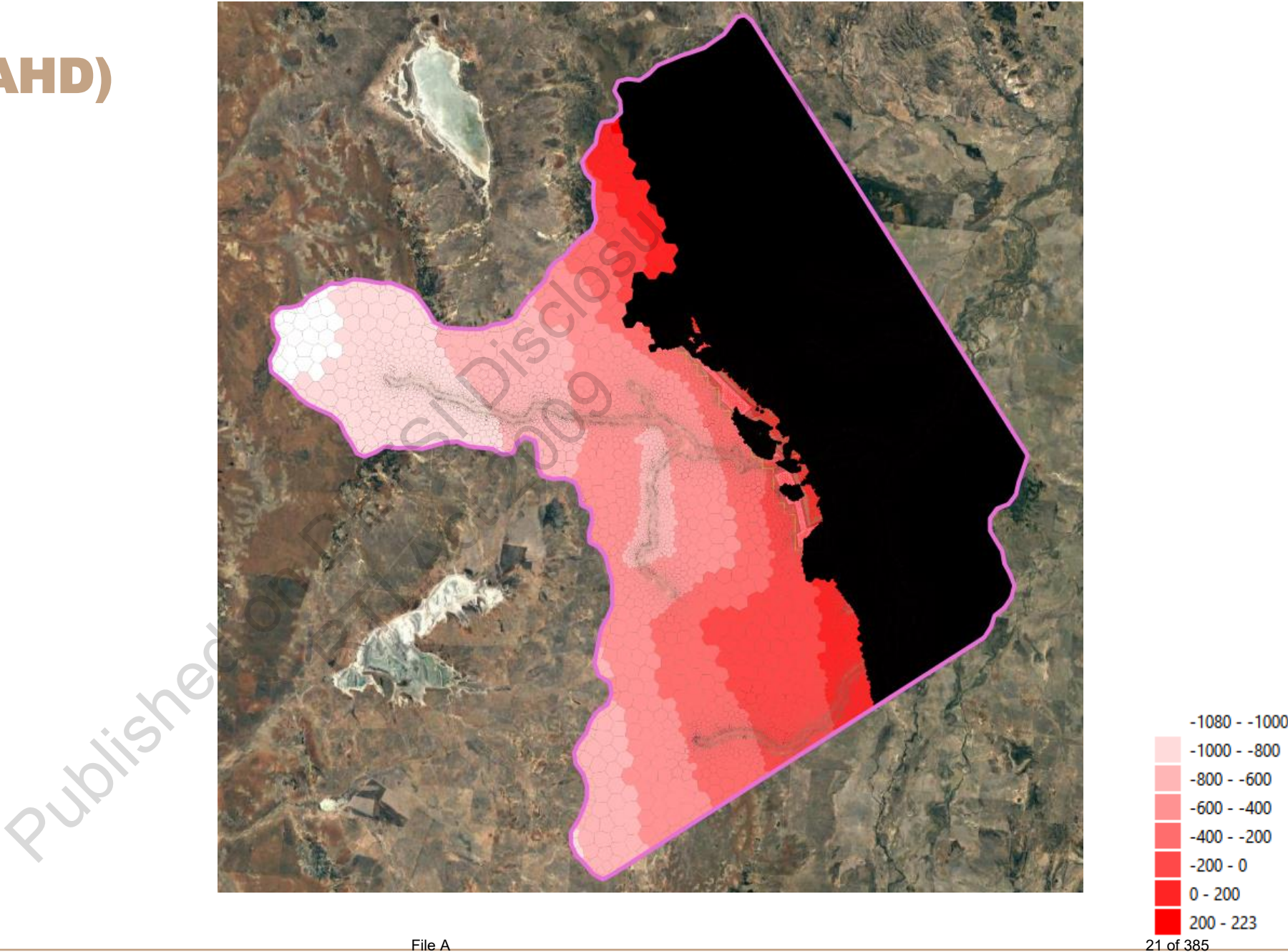
AB Coal top (mAHD)



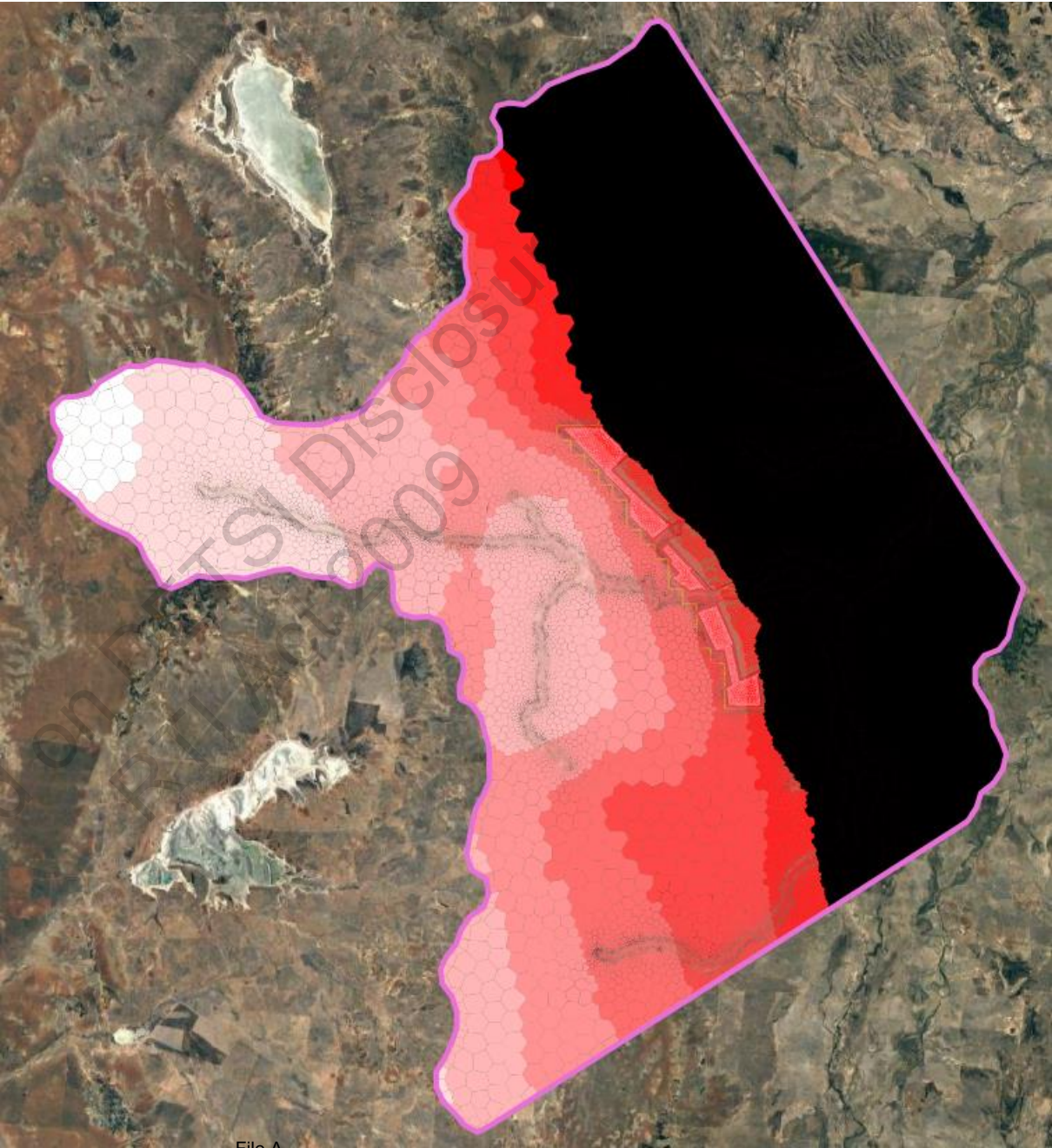
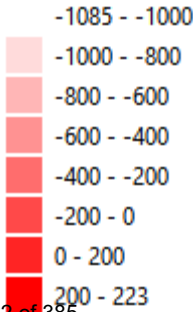
Bandanna (interburden) top (mAHD)



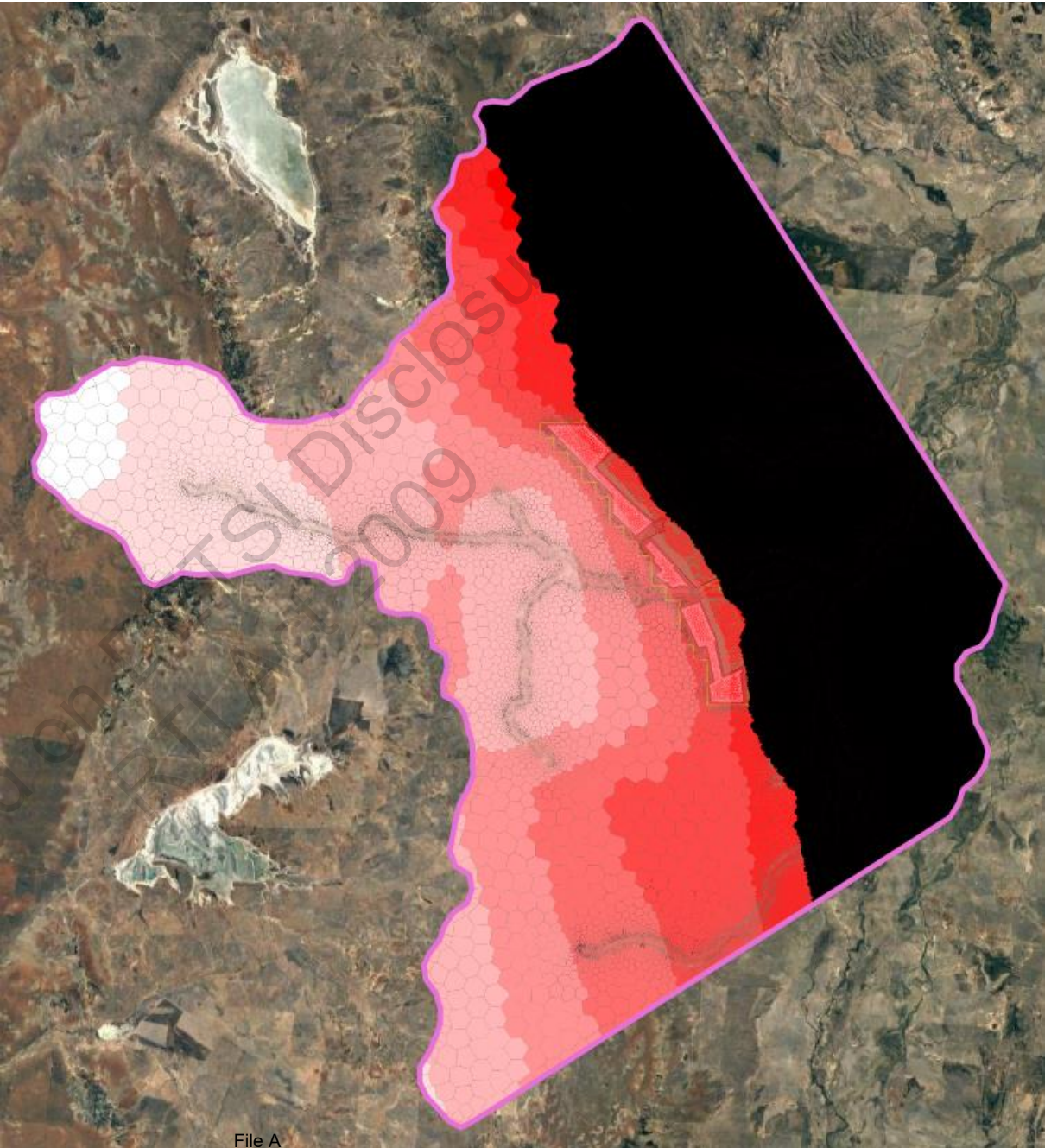
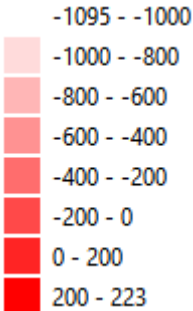
Colinlea top (mAHD)



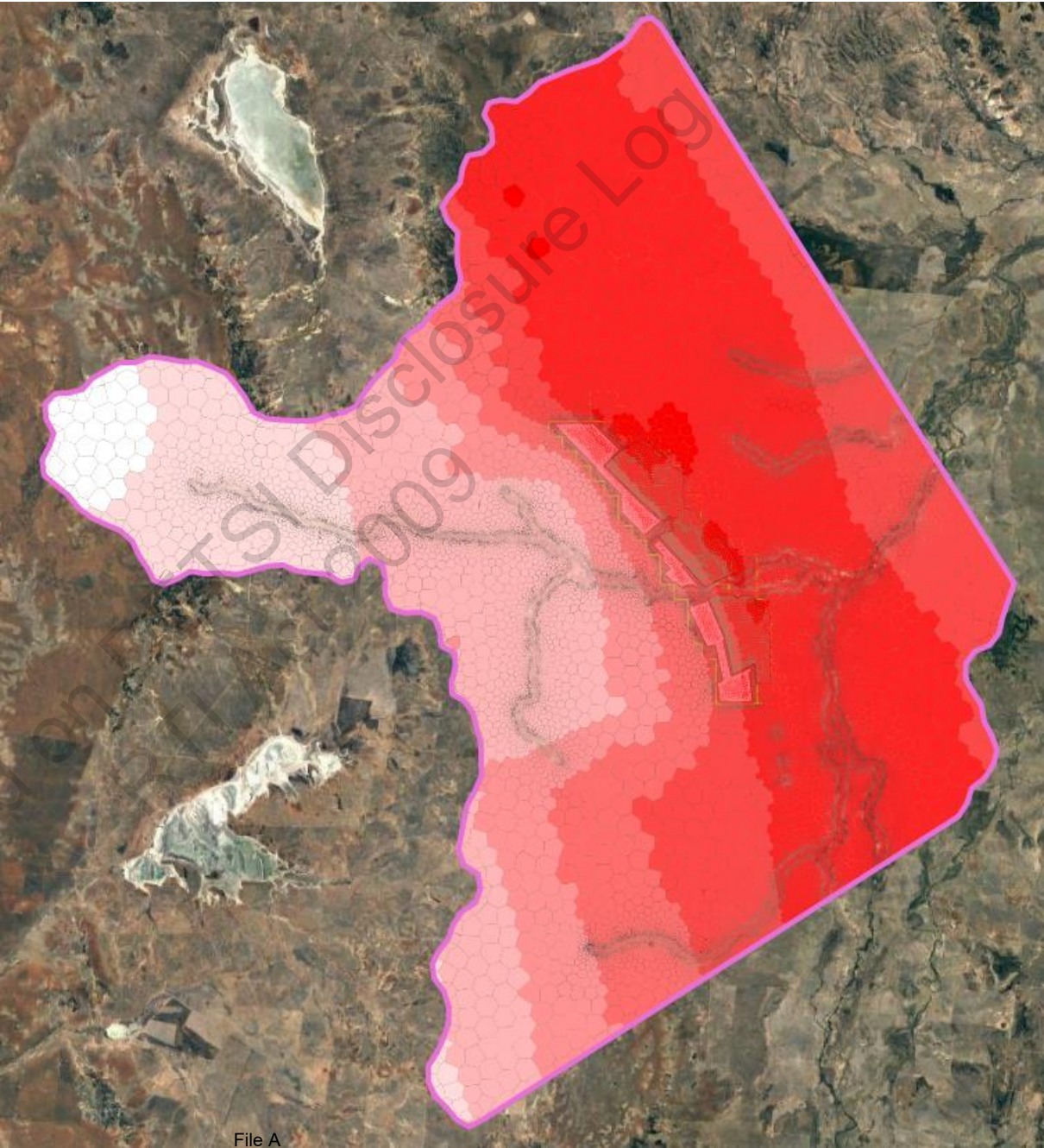
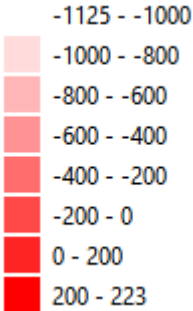
D Coal top (mAHD)



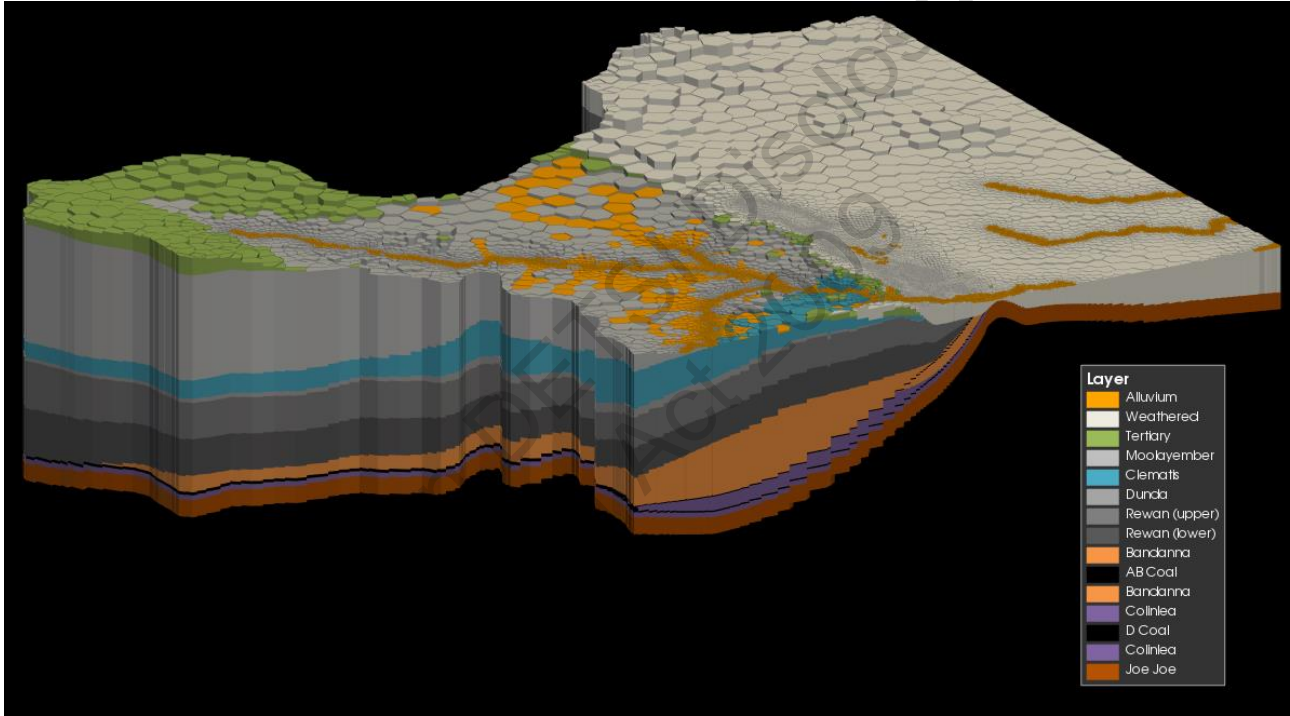
Colinlea (underburden) top (mAHD)



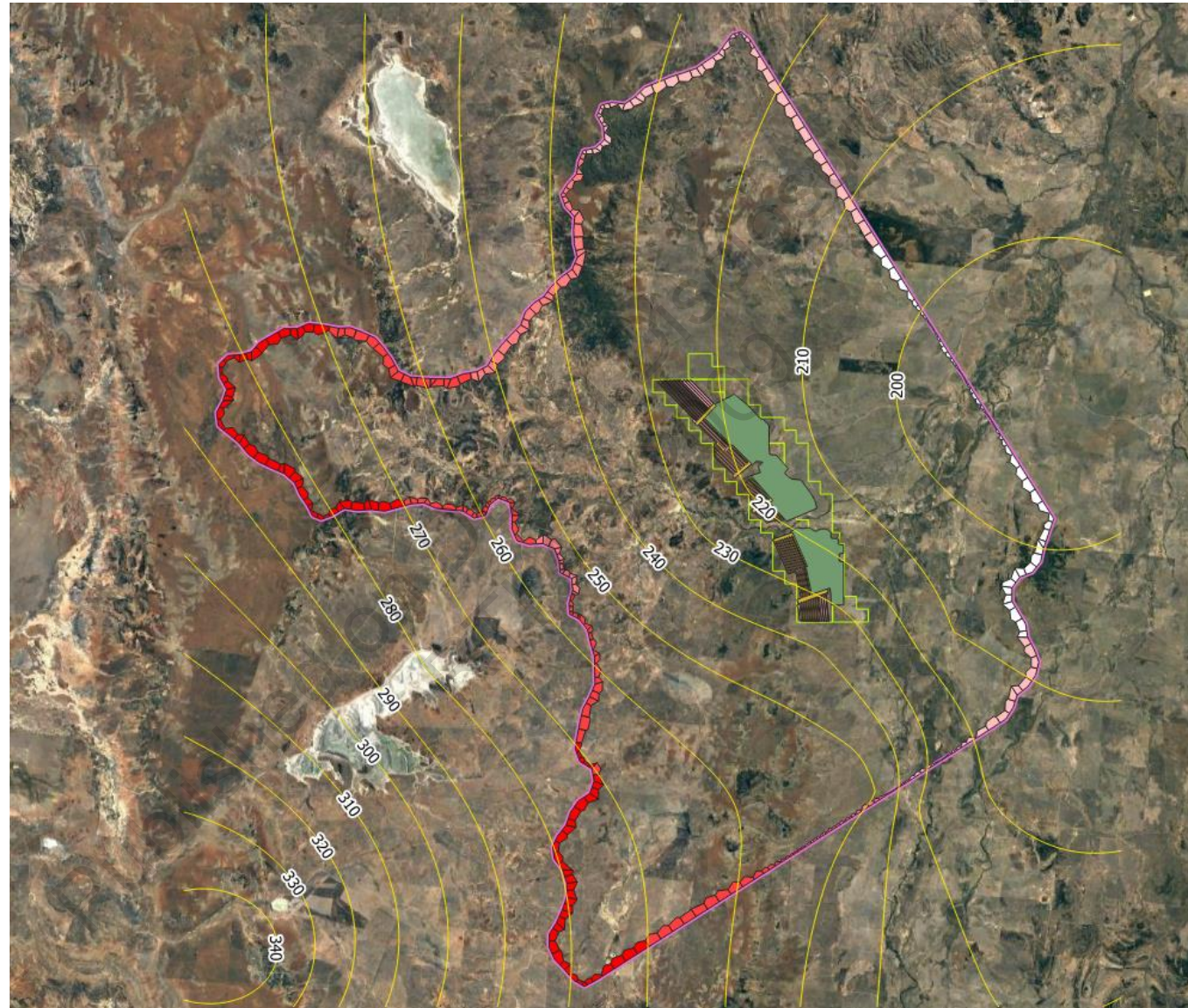
Joe Joe top (mAHD)



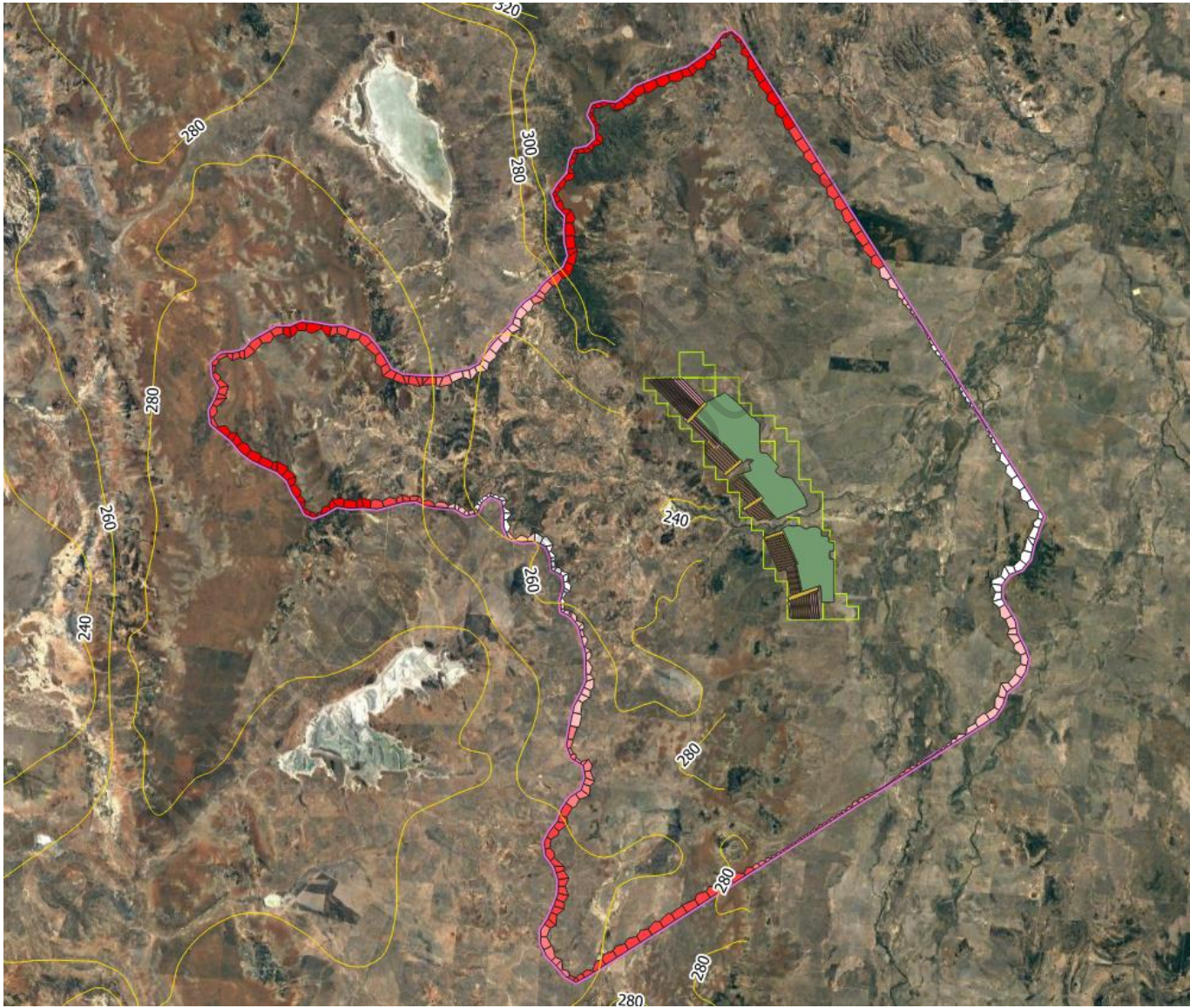
Cross section (west-east)



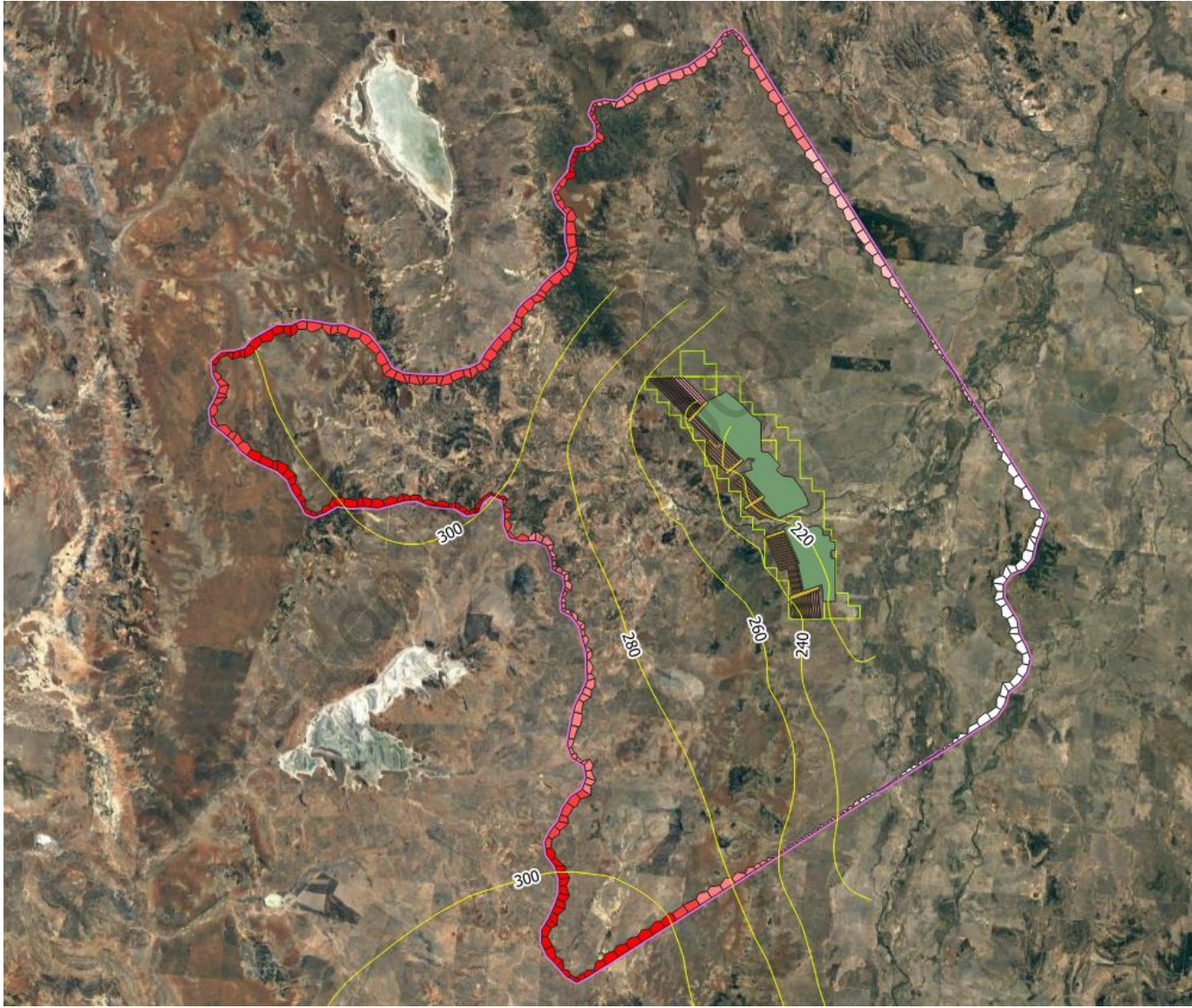
Surficial regional boundaries



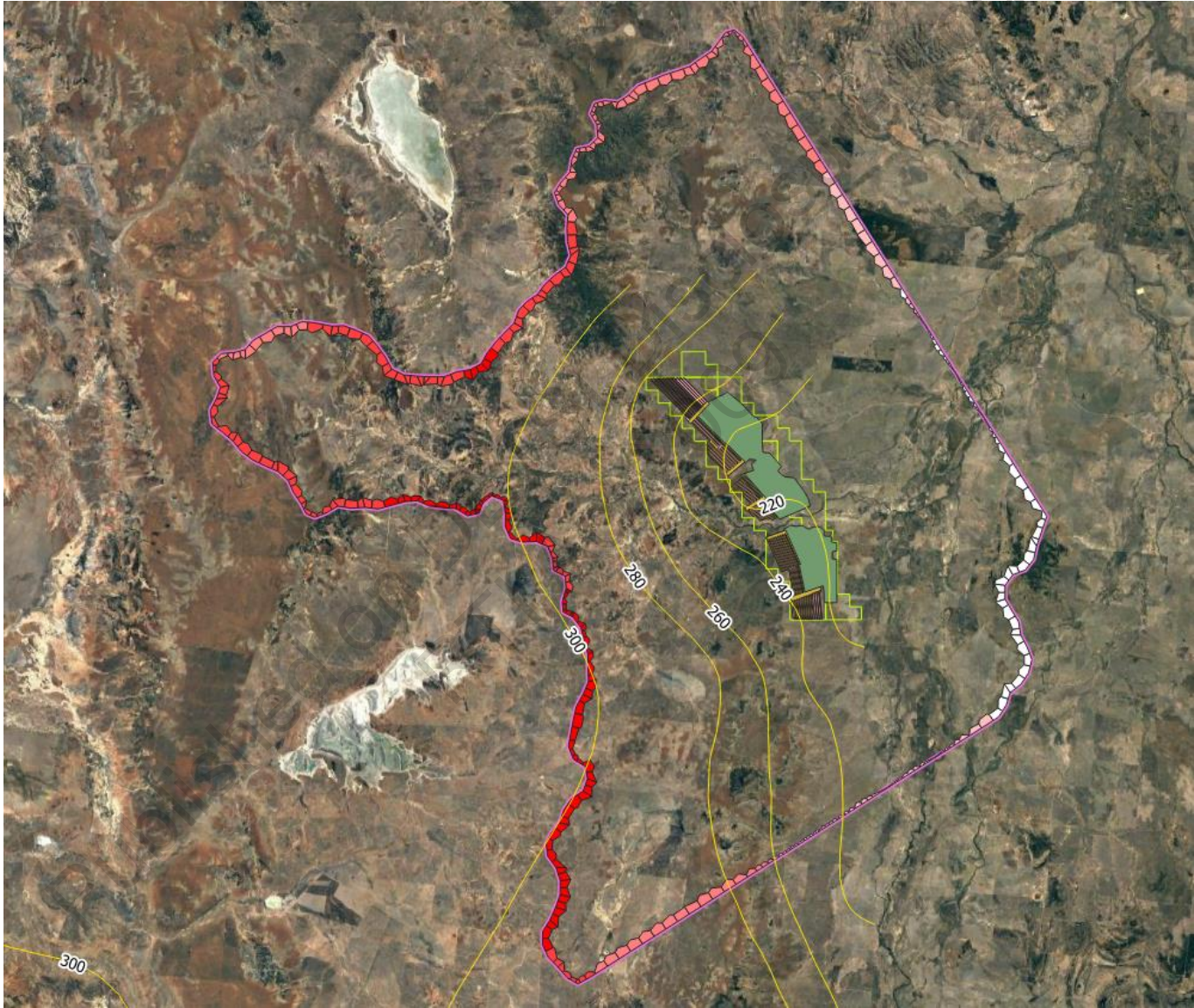
Clematis regional boundaries



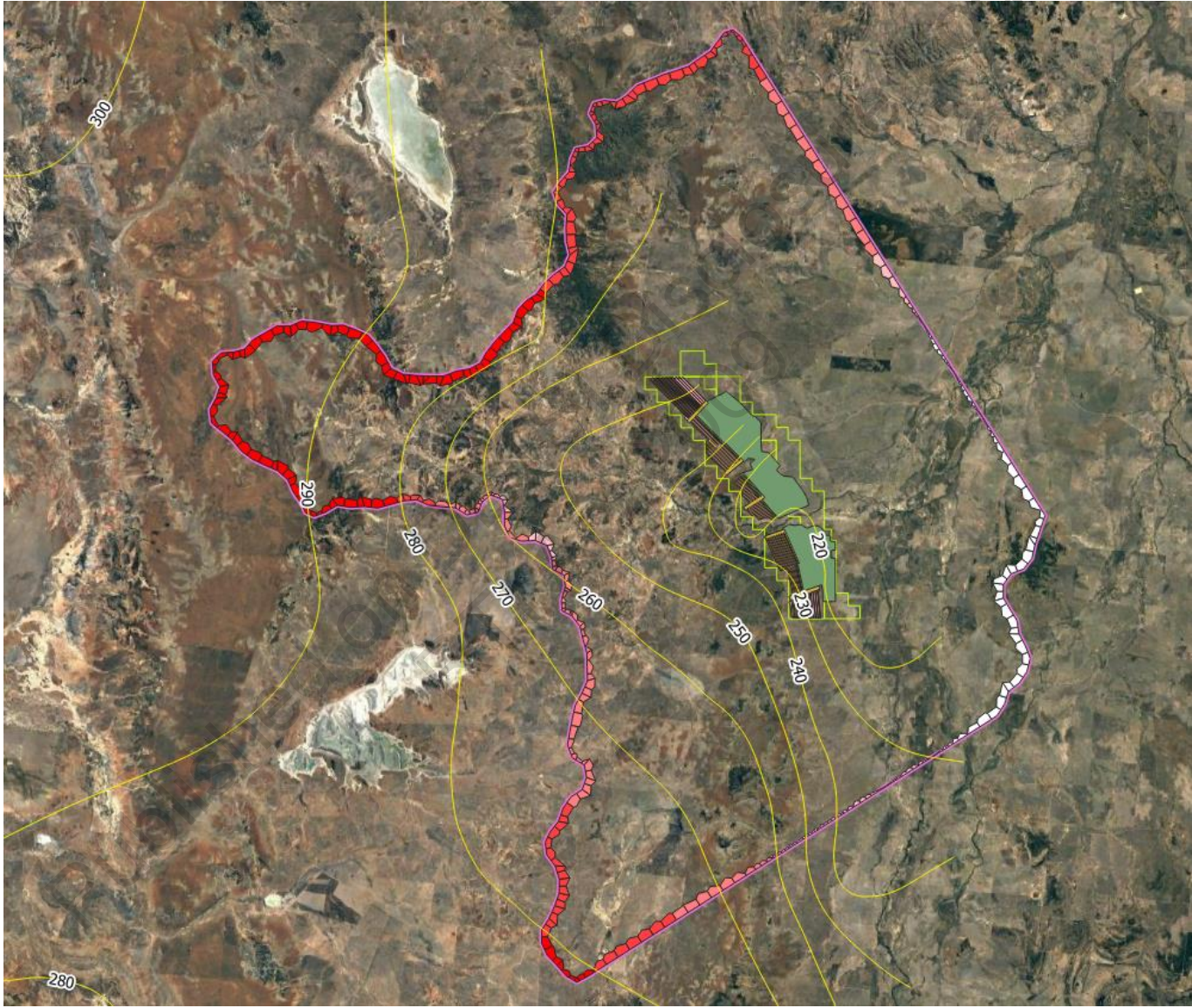
Bandanna regional boundaries



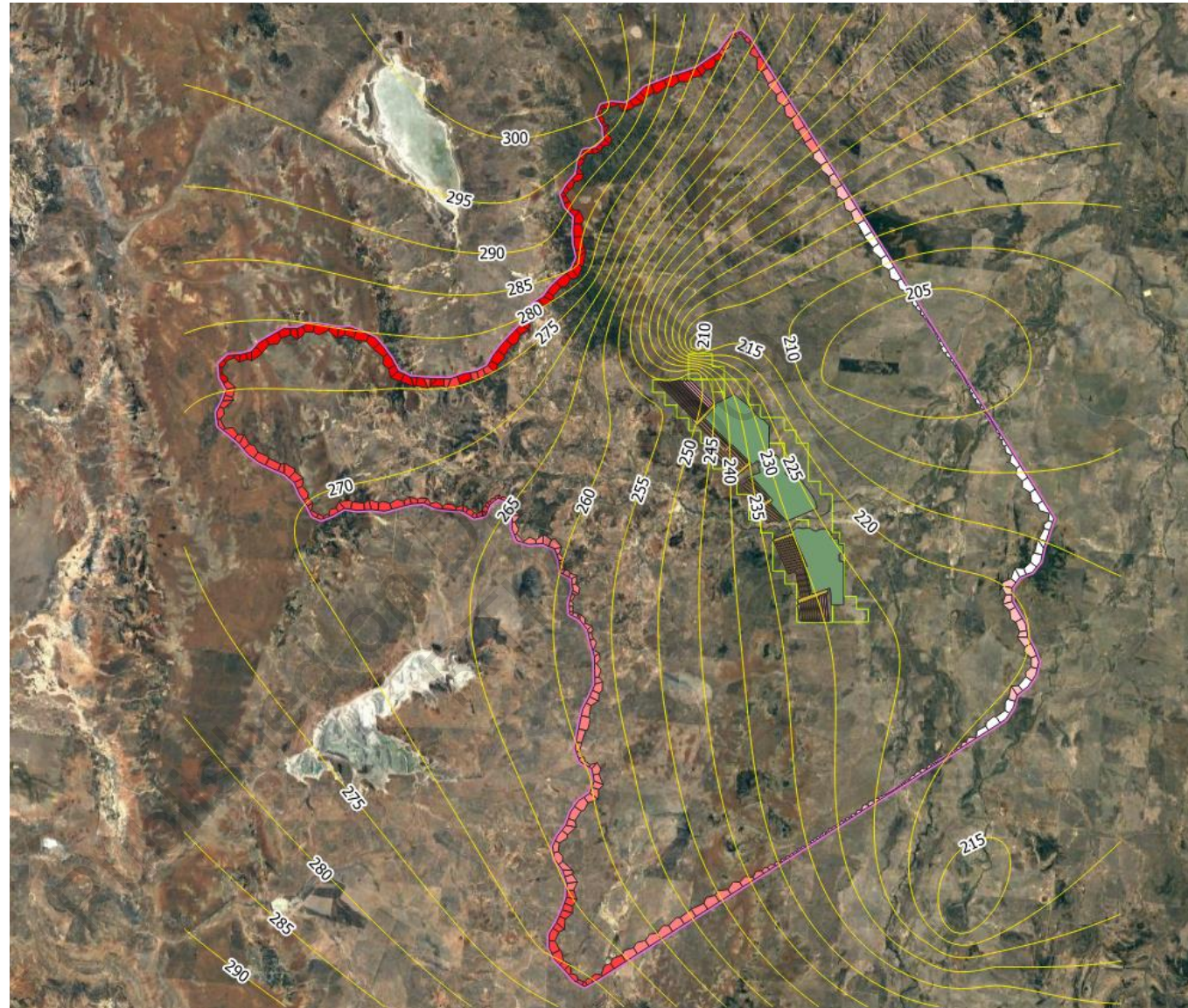
Coal seam regional boundaries



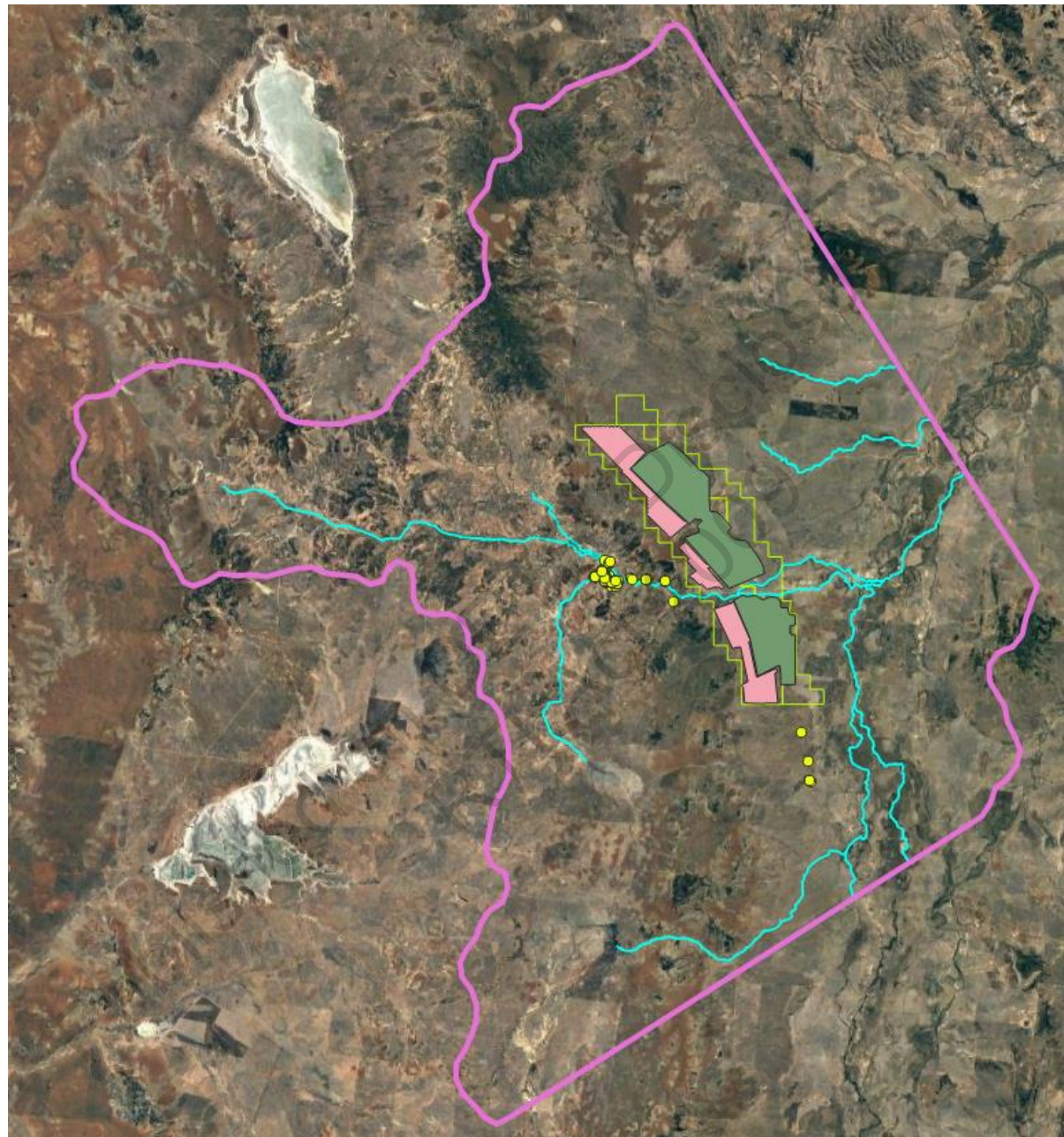
Colinlea regional boundaries



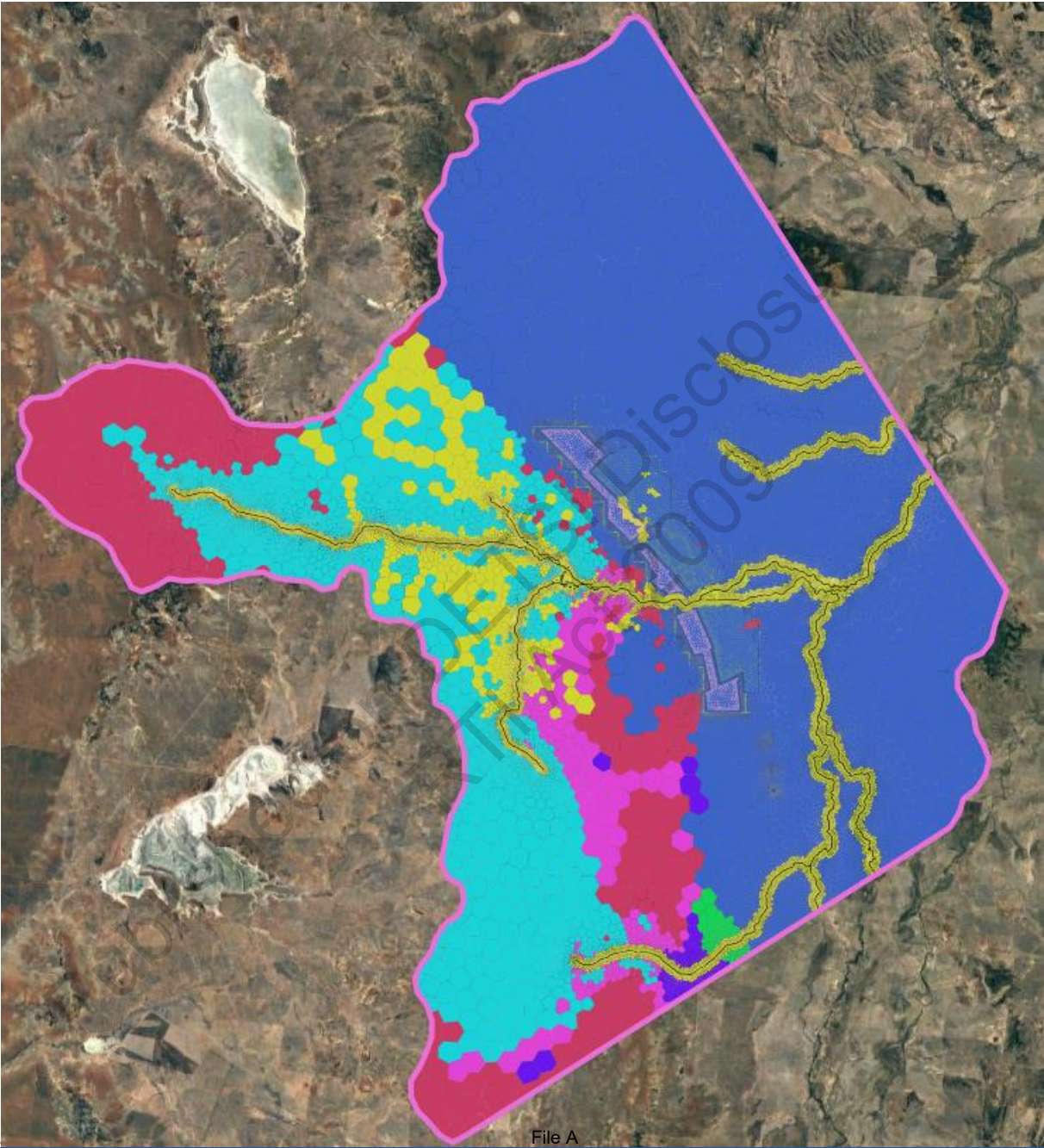
Joe Joe regional boundaries



Surface water



Recharge



- Alluvium
- Weathered
- Tertiary
- Moolayember
- Clematis
- Rewan
- Bandanna
- Inactive

BRAVUS

MINING & RESOURCES

History-matching

History-matching stresses

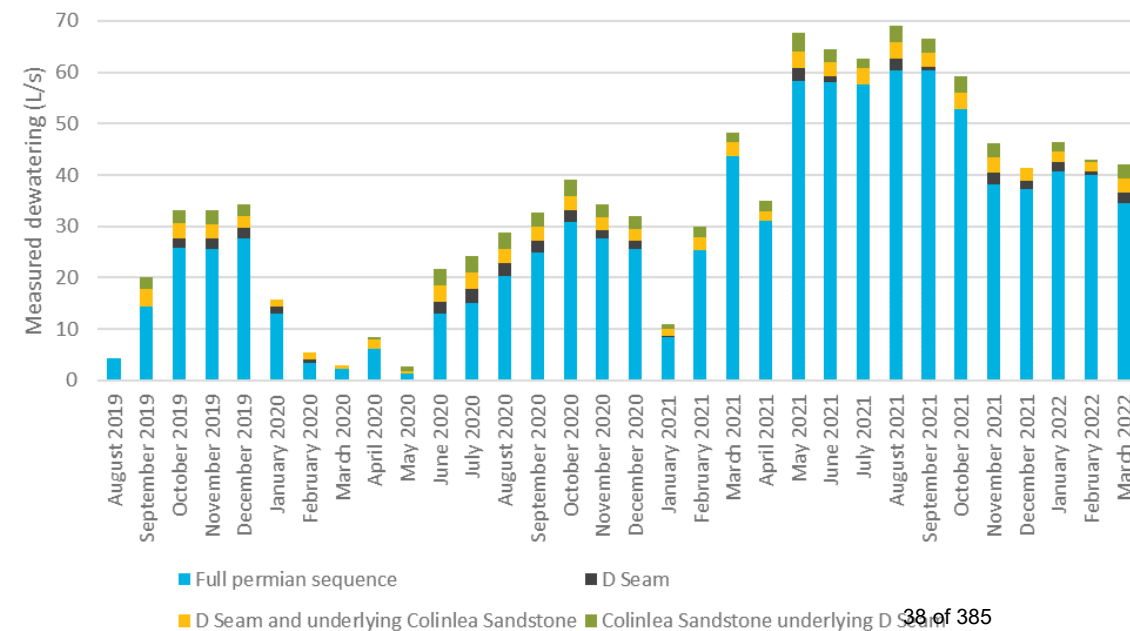
- Environmental stresses:
 - Regional throughflow
 - Watercourses, leaking to groundwater system during wet season
 - Doongmabulla/Mellaluka springs
 - Recharge to outcropping HSUs, set as a proportion of measured rainfall
 - Evapotranspiration
- Mining stresses:
 - Dewatering bores, active from August 2019, with monthly abstraction rates

Modelled watercourses

Watercourse	Depth in steady state stress period (m)	Wet season depth (m)	Dry season depth (m)
Belyando River	1.18	1.78	0
Belyando western breakout	0.59	0.89	0
Bimbah Creek	0	0	0
Carmichael River	0.30	0.70	0
Cattle Creek	0.15	0.35	0
Dunda Creek	0	0	0
Dyllingo Creek	0.15	0.35	0
Dyllingo northern breakout	0	0	0
North Creek	0	0	0
Tomahawk Creek	0	0	0

Modelled recharge and evapotranspiration

- Recharge calculated per stress period based on measured rainfall data at Ulcanbah station, with a PEST-estimated multiplier applied per outcropping HSU resulting in the following annual average recharge rates:
 - Quaternary alluvium: 0.009 mm/year (plus recharge from watercourse leakage and springs discharging to surface)
 - Weathering zone: 0.002 mm/year
 - Tertiary and non-alluvial Quaternary deposits: 0.083 mm/year
 - Moolayember Formation: 0.003 mm/year
 - Clematis Sandstone / Warang Sandstone: 0.194 mm/year
 - Rewan Formation: 0.001 mm/year
 - Bandanna Formation: 0.001 mm/year
- Evapotranspiration applied per stress period with a maximum rate equal to pan evaporation, with an extinction depth of 1.4 m regionally and 6 m in highly vegetated riverine areas

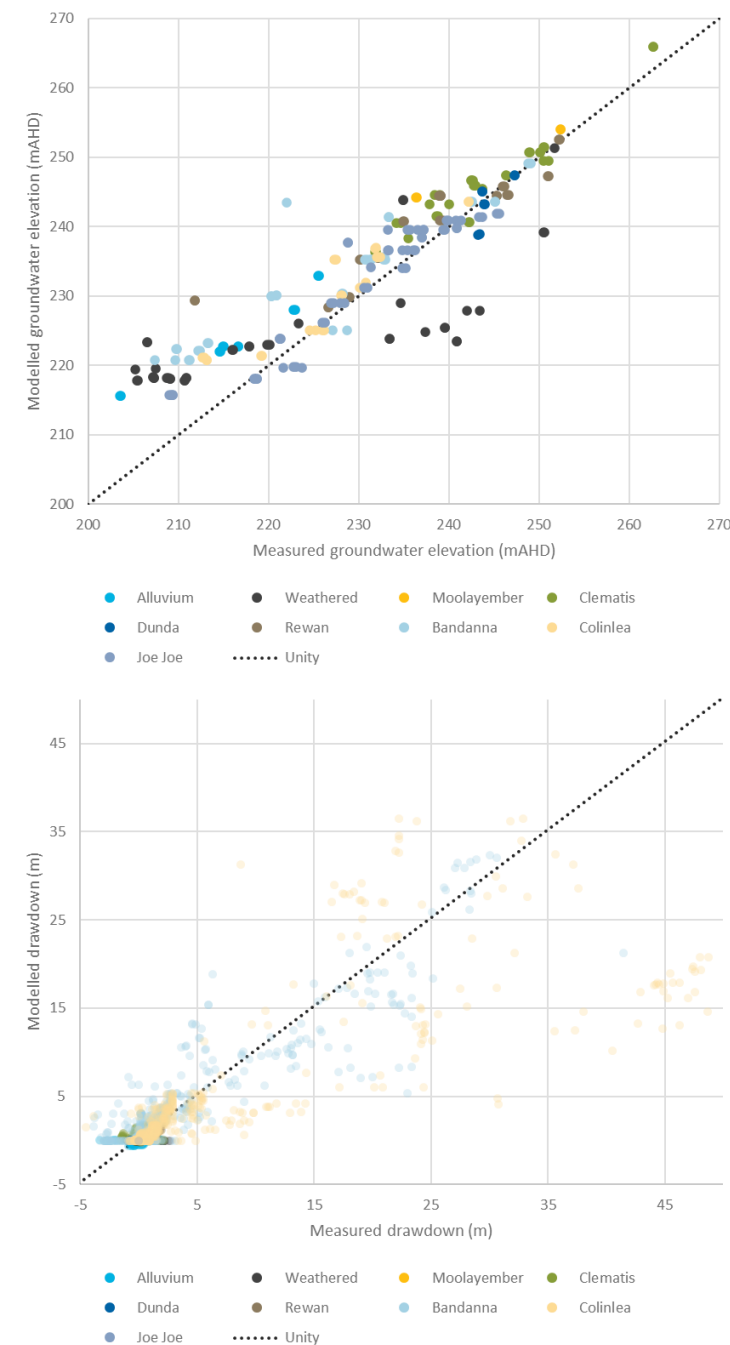


History-matching detailed process

- Set up model with expected hydraulic properties based on hydrogeological conceptual model
- Define measured groundwater level data and estimates of spring flux as targets
 - Group targets by HSU, using first transient measurement as a 'head' target, and the remainder as 'head-change' targets
- Run model to calculate starting objective function
- Re-weight targets such that each target group (head and head-change per HSU, spring flux) contributes an equal amount to the starting objective function
- Run PEST on parameter zones, giving homogeneous values as a starting point for **highly parameterised** history-matching
- Set up **pilot points (>30,000)** with parameter bounds based on conceptualisation with additional range (up to an order of magnitude) to account for smaller scale heterogeneities
- Re-weight targets as per point 4 above, for new starting point
- Run **PESTPP-IES for 10 iterations**, with 500 realisations
- Review model parameters against conceptualisation, and make adjustments accordingly (e.g. limit anisotropy ratio)
- Run model with updated parameters to ensure performance against targets is not substantially degraded
- Run **PESTPP-IES for 1 more iteration**; further improving history-matching performance and developing a suite of parameter values that can be used for predictive uncertainty analysis

History-matching performance: base case

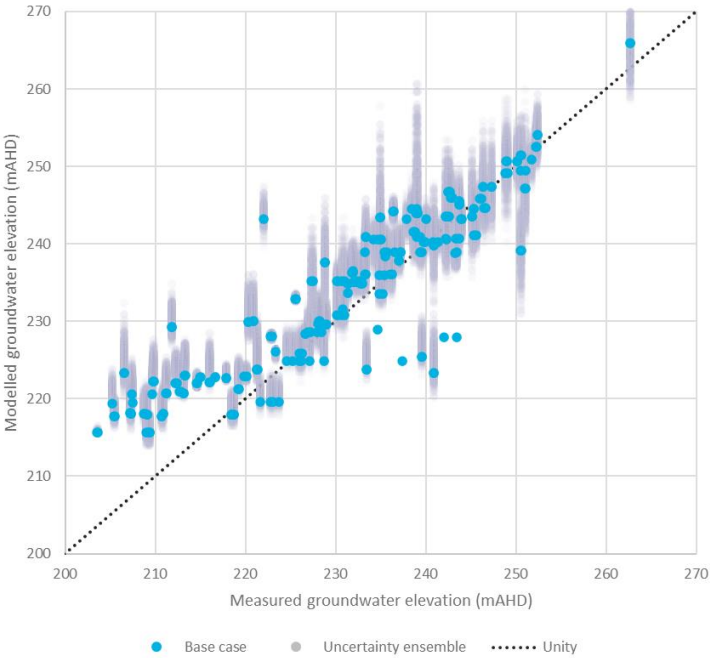
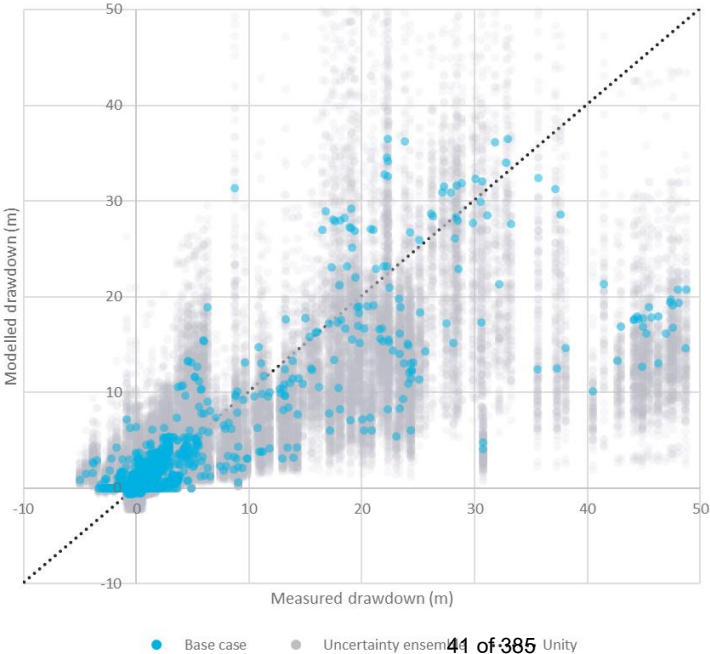
- History-matching undertaken on weighted head and head-change targets
- Performance reported against **unweighted head values**
- **SRMS 6.7%**
- Mean residual -3.6 m
- Mean absolute residual 4.8 m
- Minimum residual -39.4 m
- Maximum residual 17.5 m
- Number of observations 11,441
- Range of observations 93.5 m
- Flux targets:
- Joshua Spring
 - Estimated flux 1 ML/d
 - Modelled flux 0.91 ML/d
- Other DSC fluxes
 - Estimated flux 0.4 ML/d
 - Modelled flux 0.57 ML/d



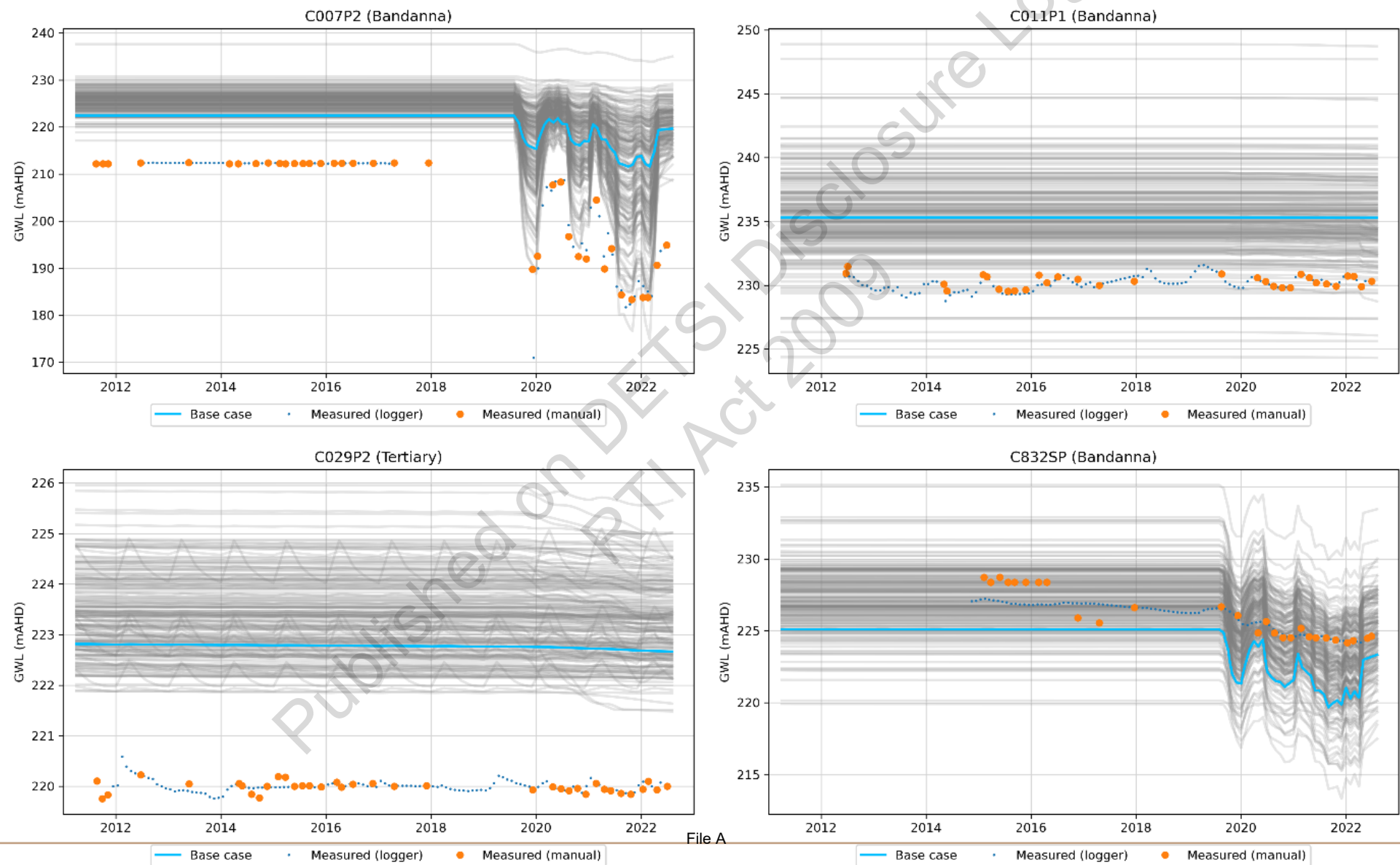
History-matching performance: ensemble

SRMS error	Initial head	Transient head-change	Transient head
Base realisation	10.9%	3.4%	6.7%
Maximum	14.1%	4.7%	8.9%
90 th percentile	13.0%	3.8%	8.2%
Median	12.1%	3.3%	7.5%
10 th percentile	11.4%	2.9%	7.0%
Minimum	10.5%	2.5%	6.3%

- Performance acceptance criteria adopted for predictive ensemble:
 - Initial hydraulic head SRMS 12.5%
 - Transient head-change SRMS 3.5%
 - Transient head SRMS 8.0%
- 500 parameter realisations
- 164 non-convergences
- 231 rejected on performance
- **105**/500 realisations accepted

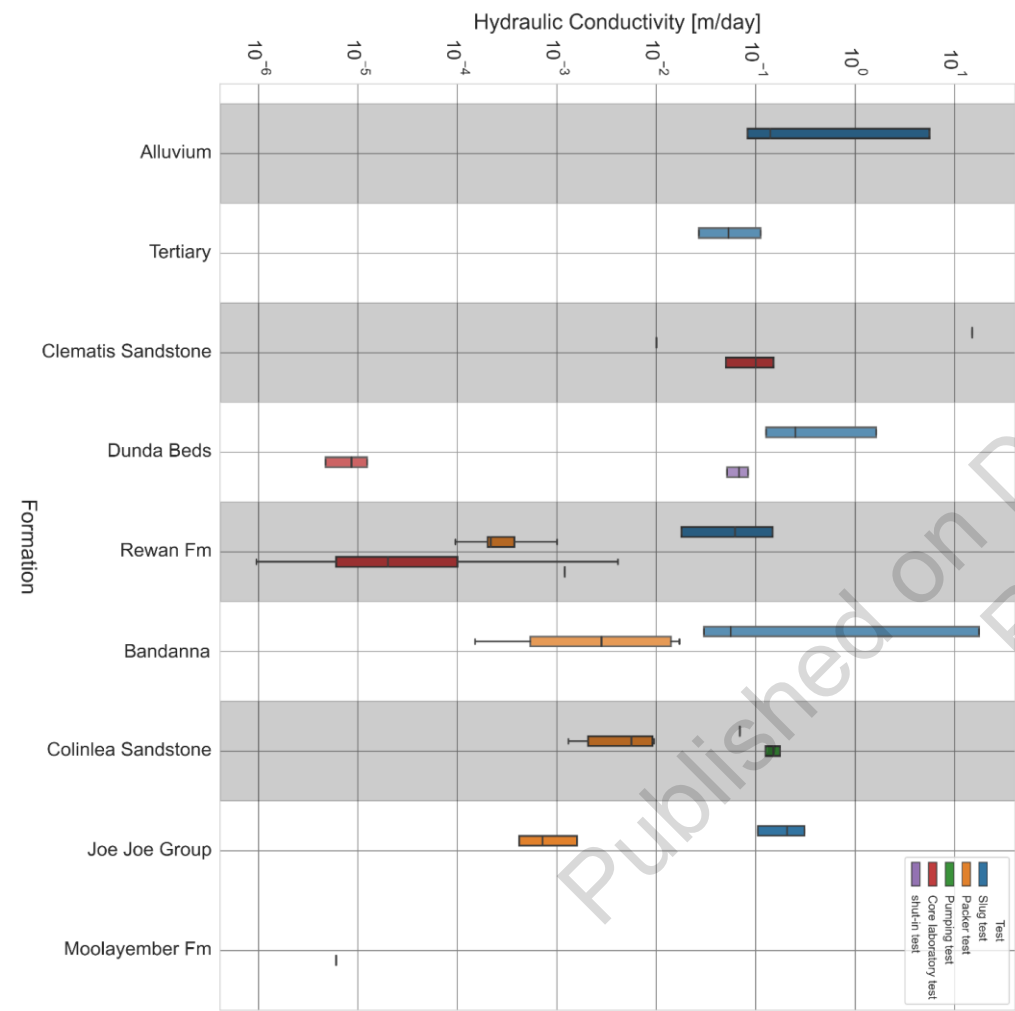


History-matching: example hydrographs

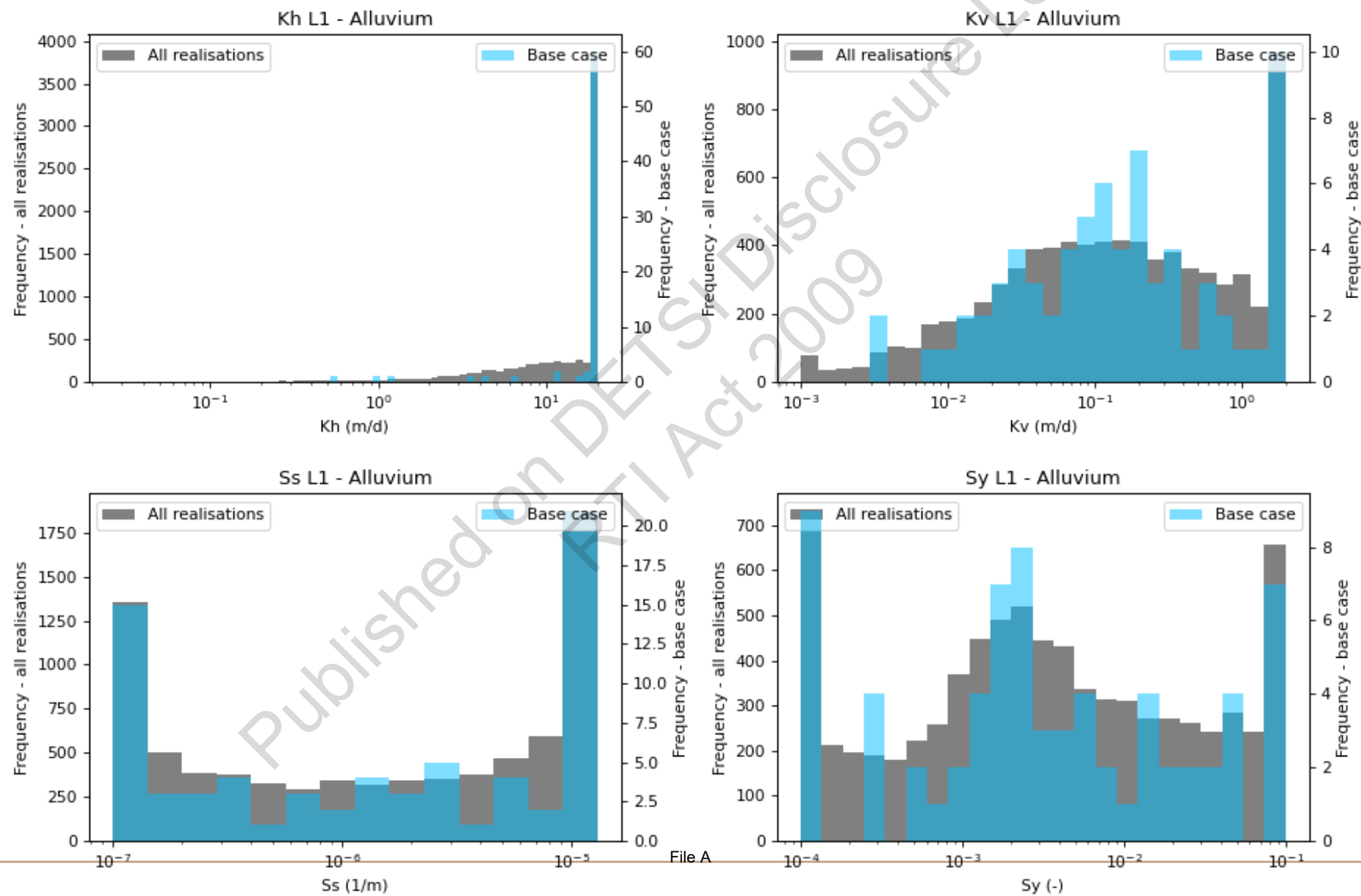


Parameterisation

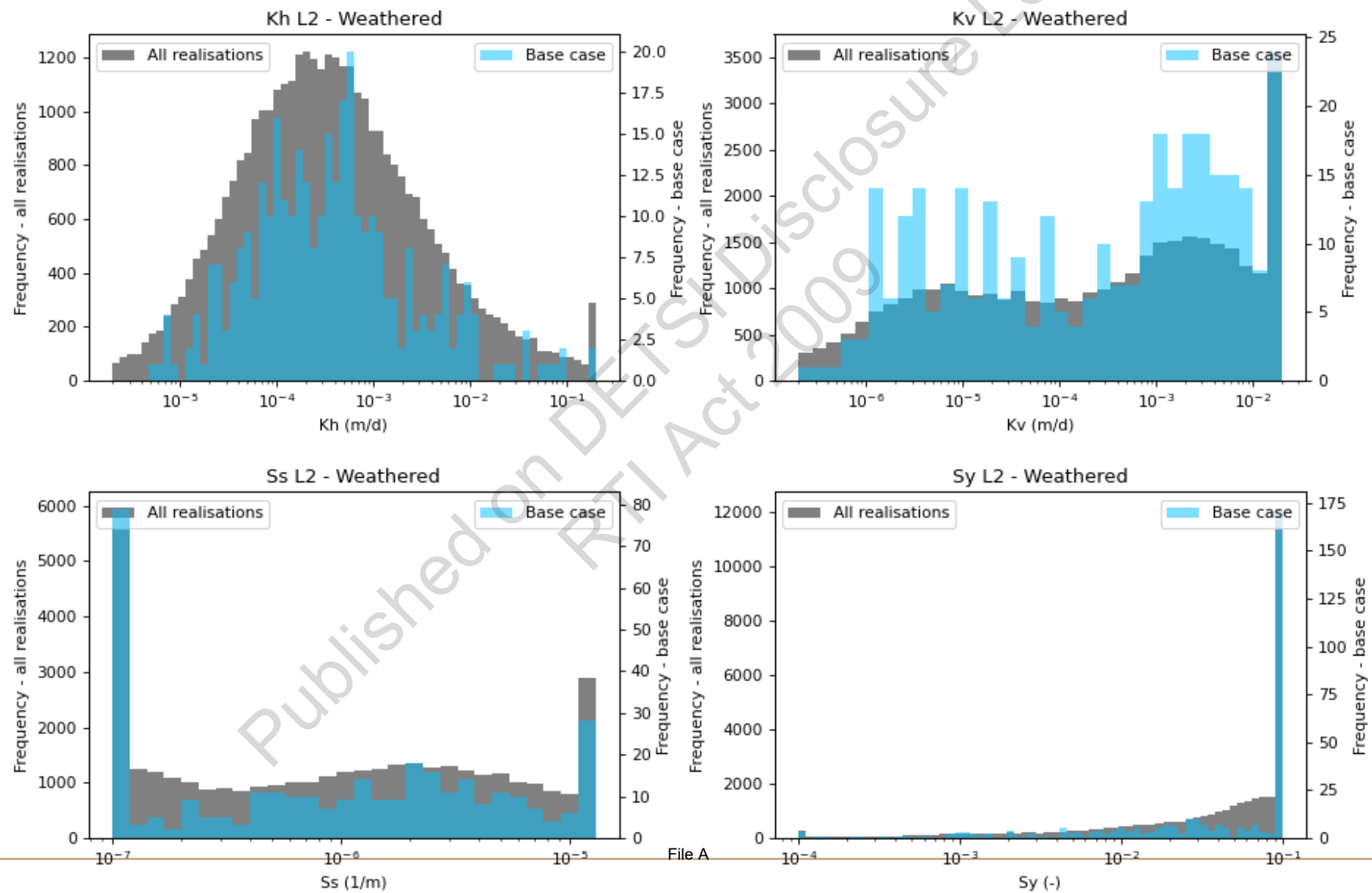
Interpreted hydraulic conductivity



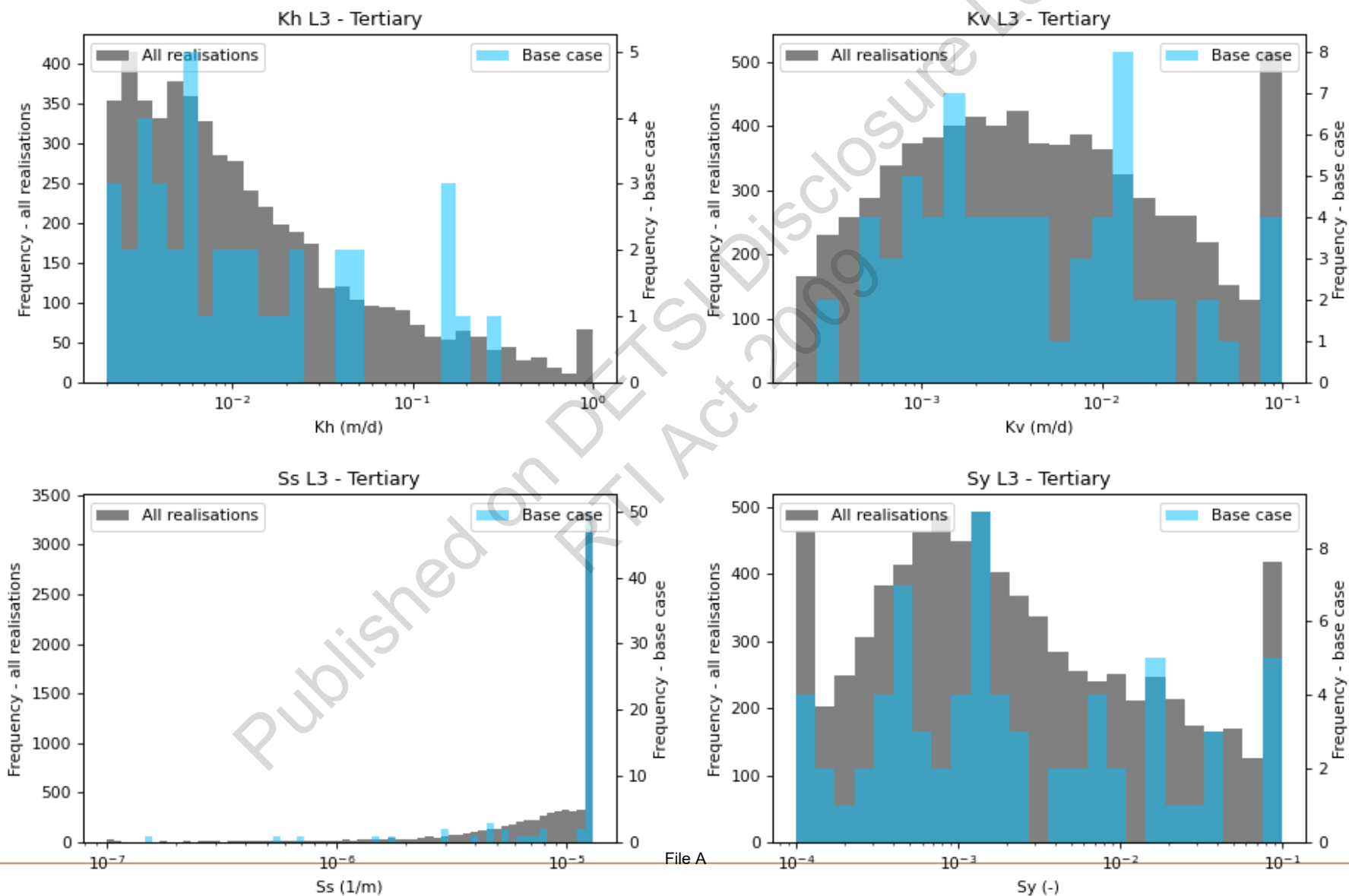
Parameterisation – L1 Alluvium



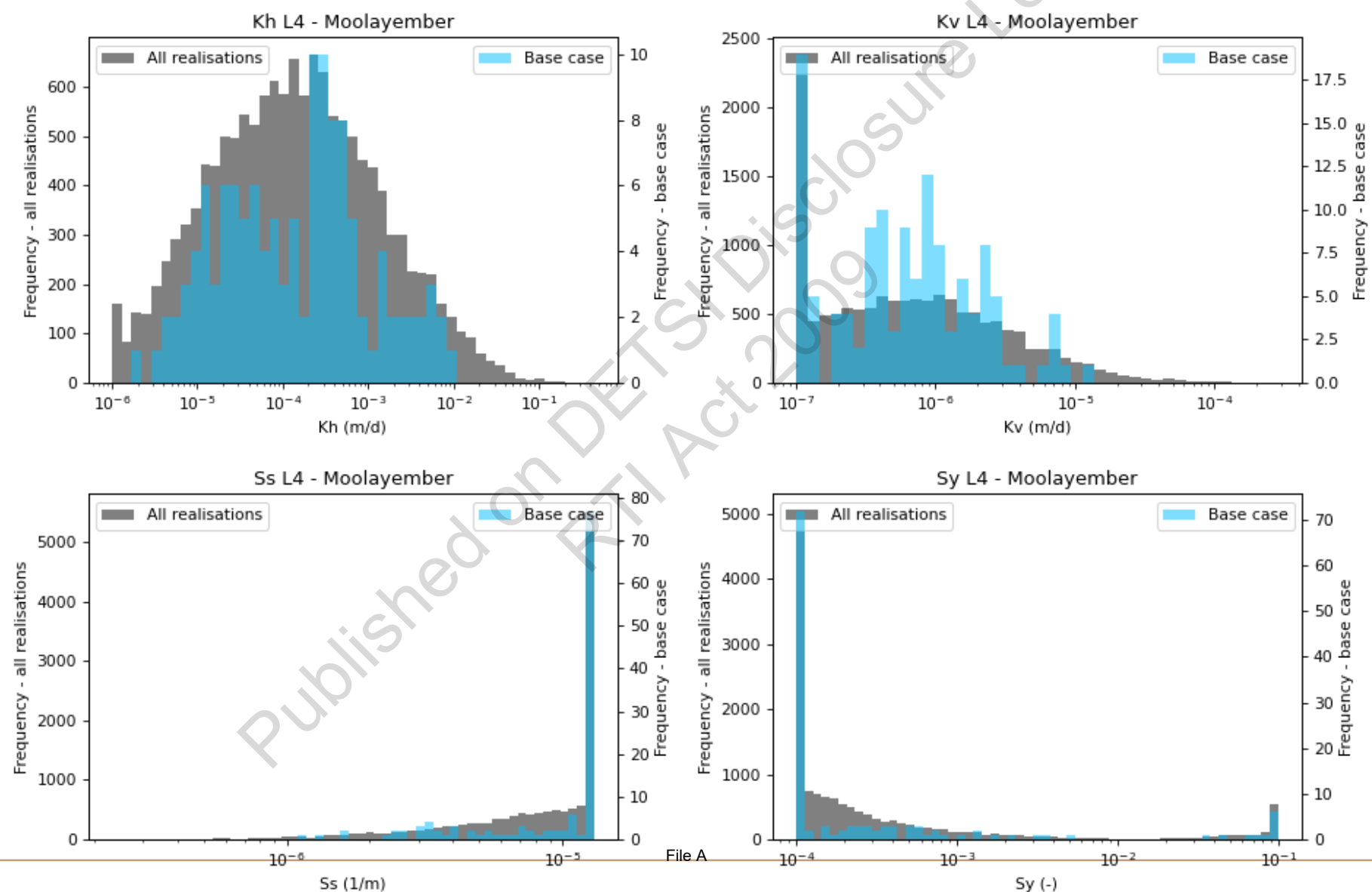
Parameterisation – L2 Weathered



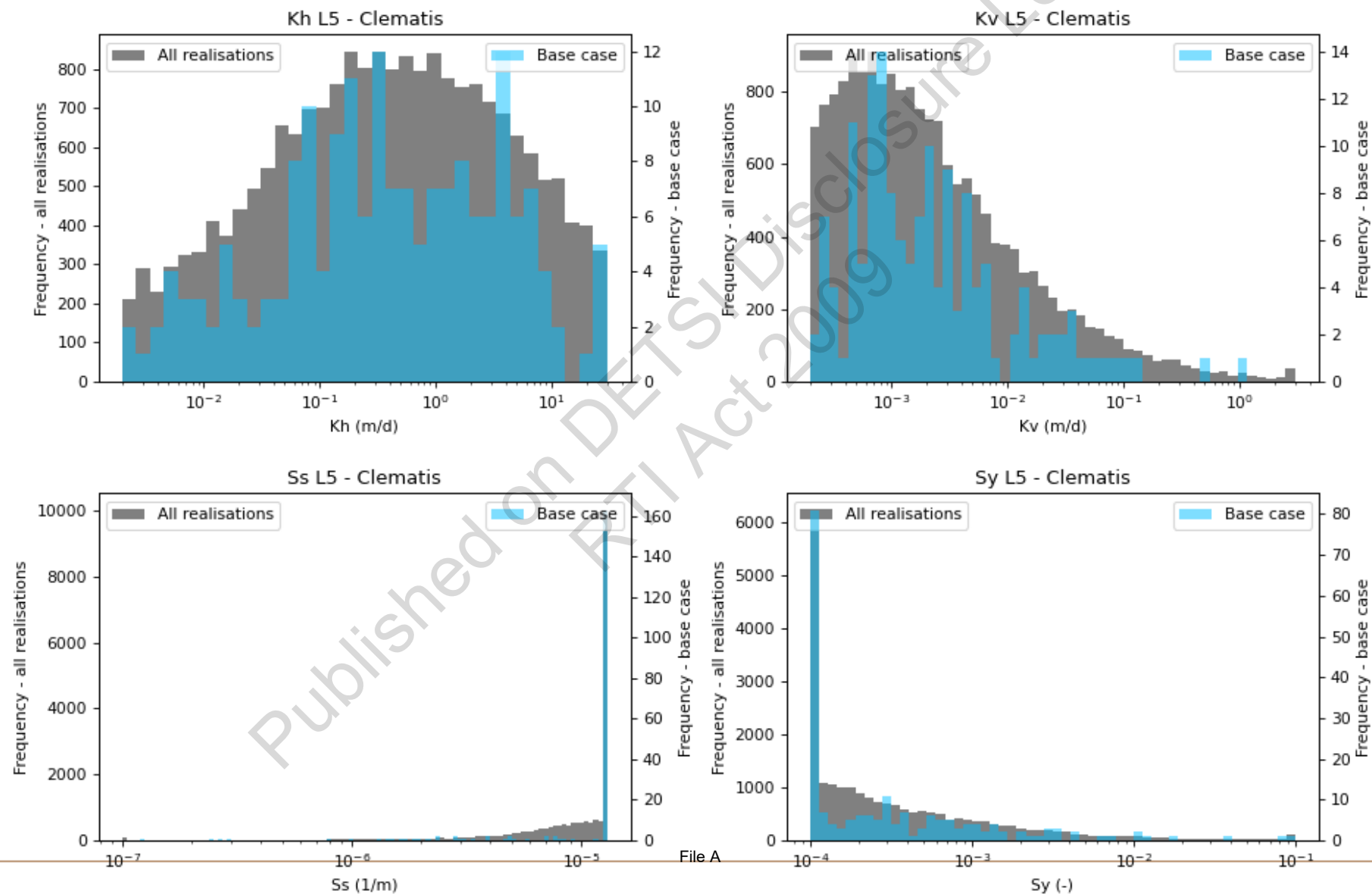
Parameterisation – L3 Tertiary



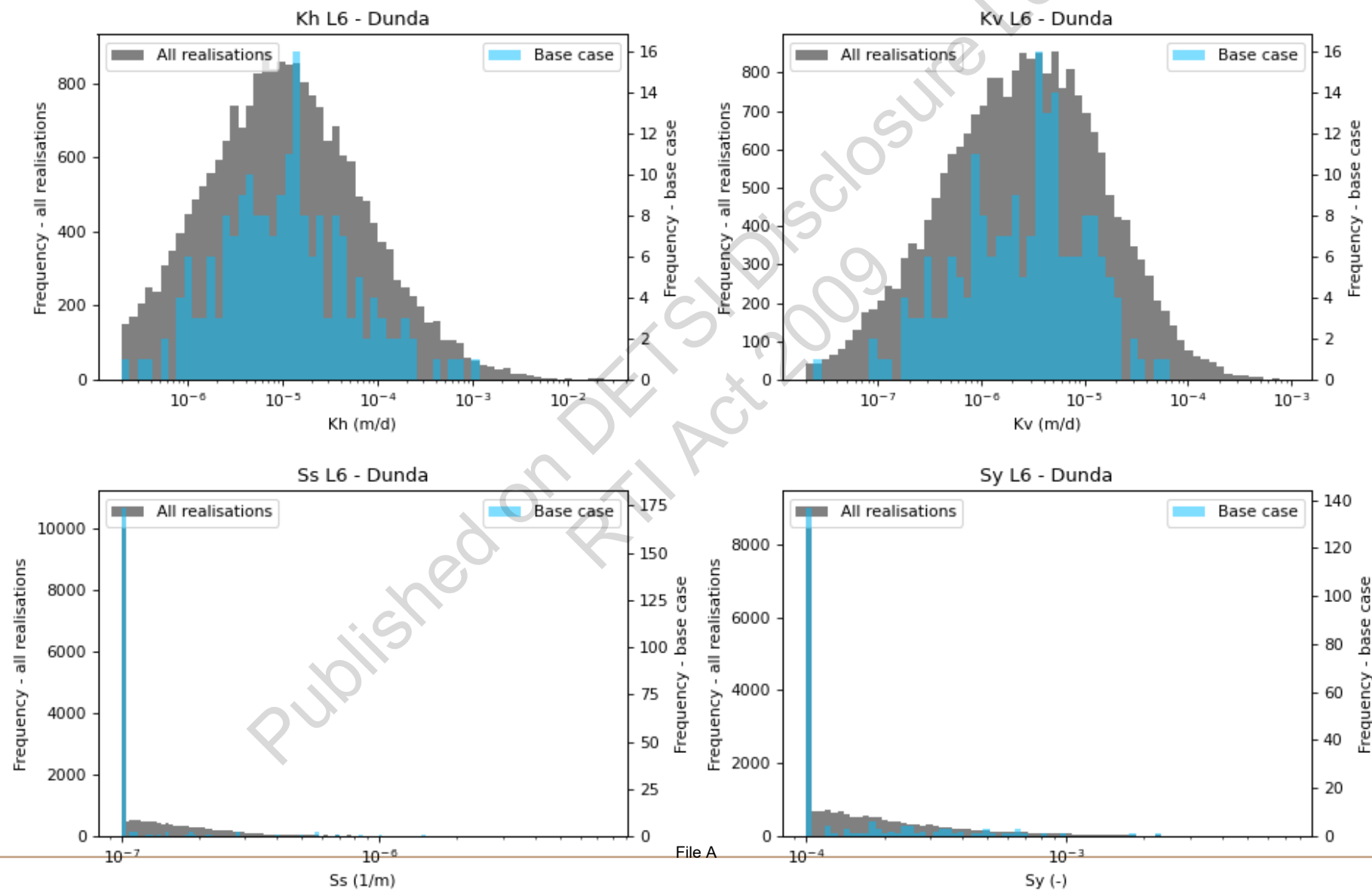
Parameterisation – L4 Moolayember



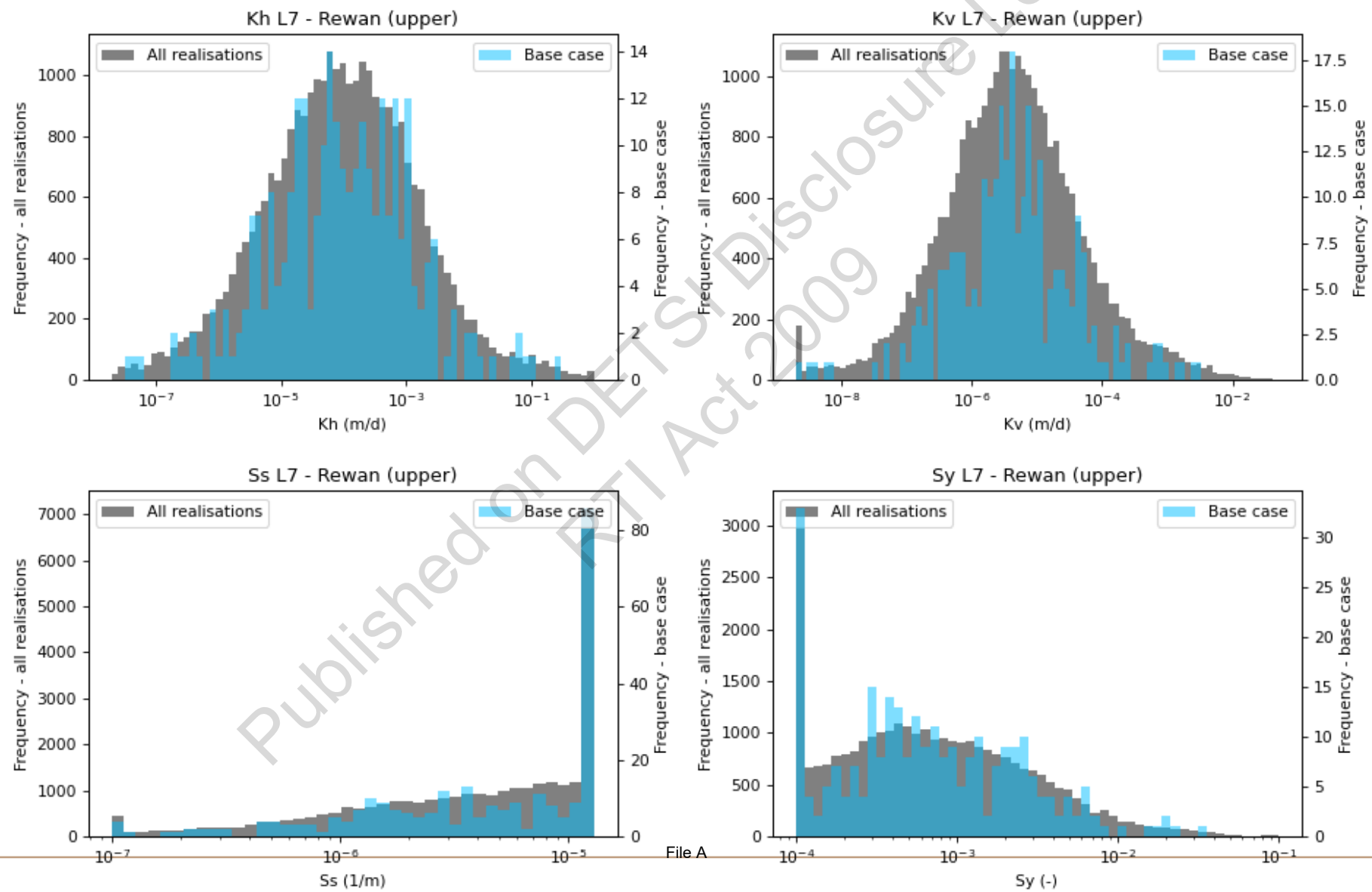
Parameterisation – L5 Clematis



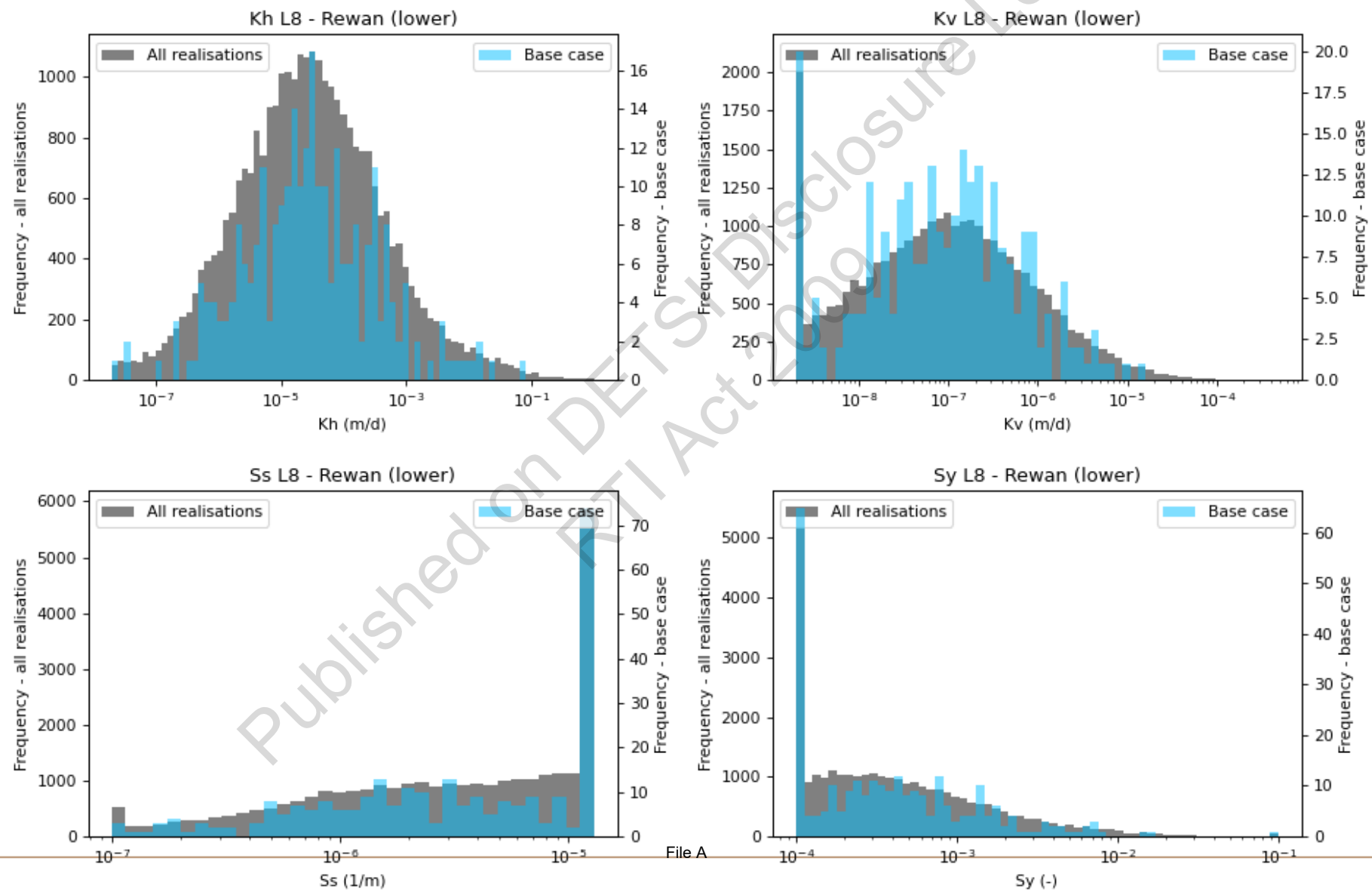
Parameterisation – L6 Dunda



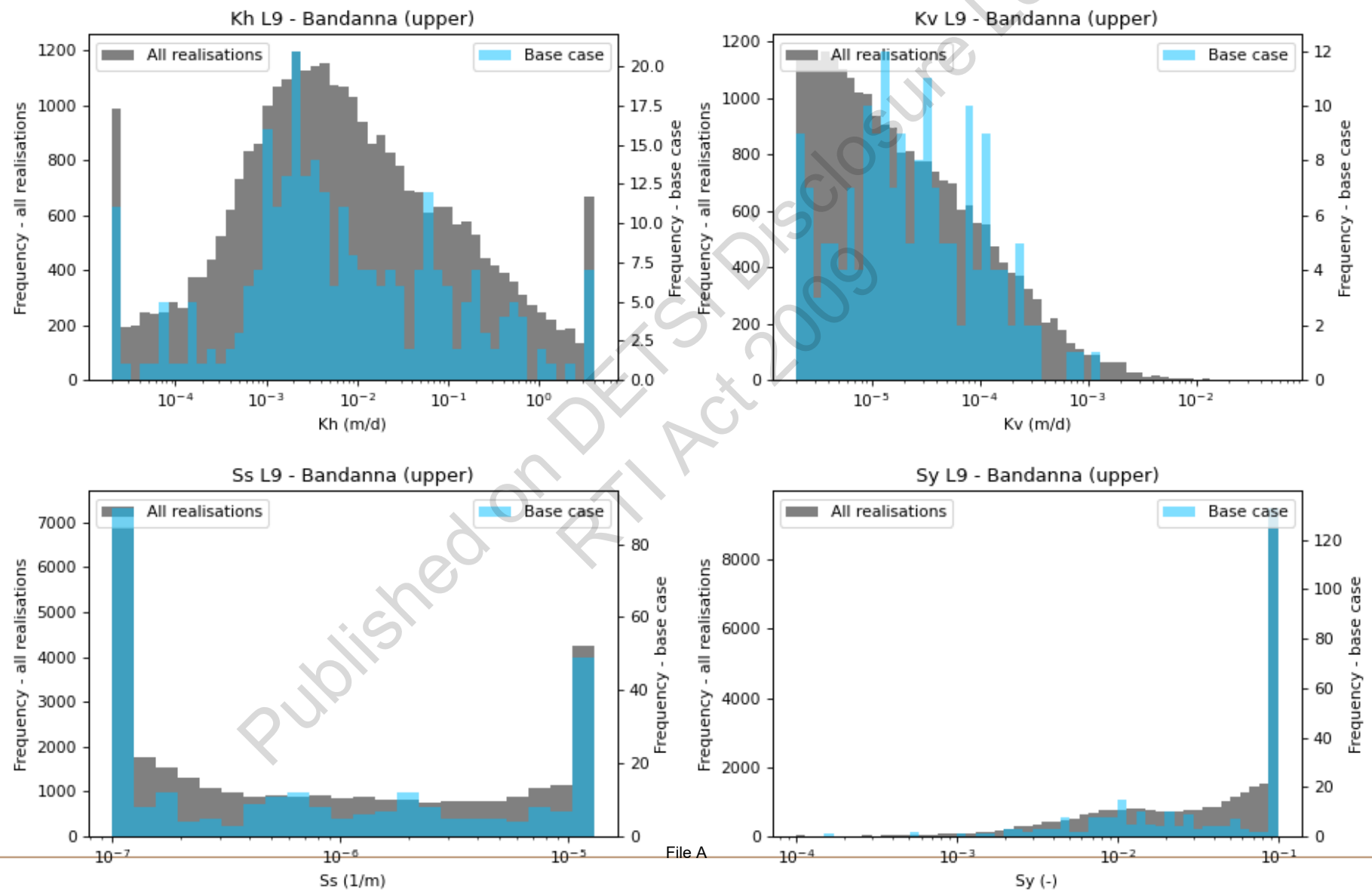
Parameterisation – L7 Rewan (upper)



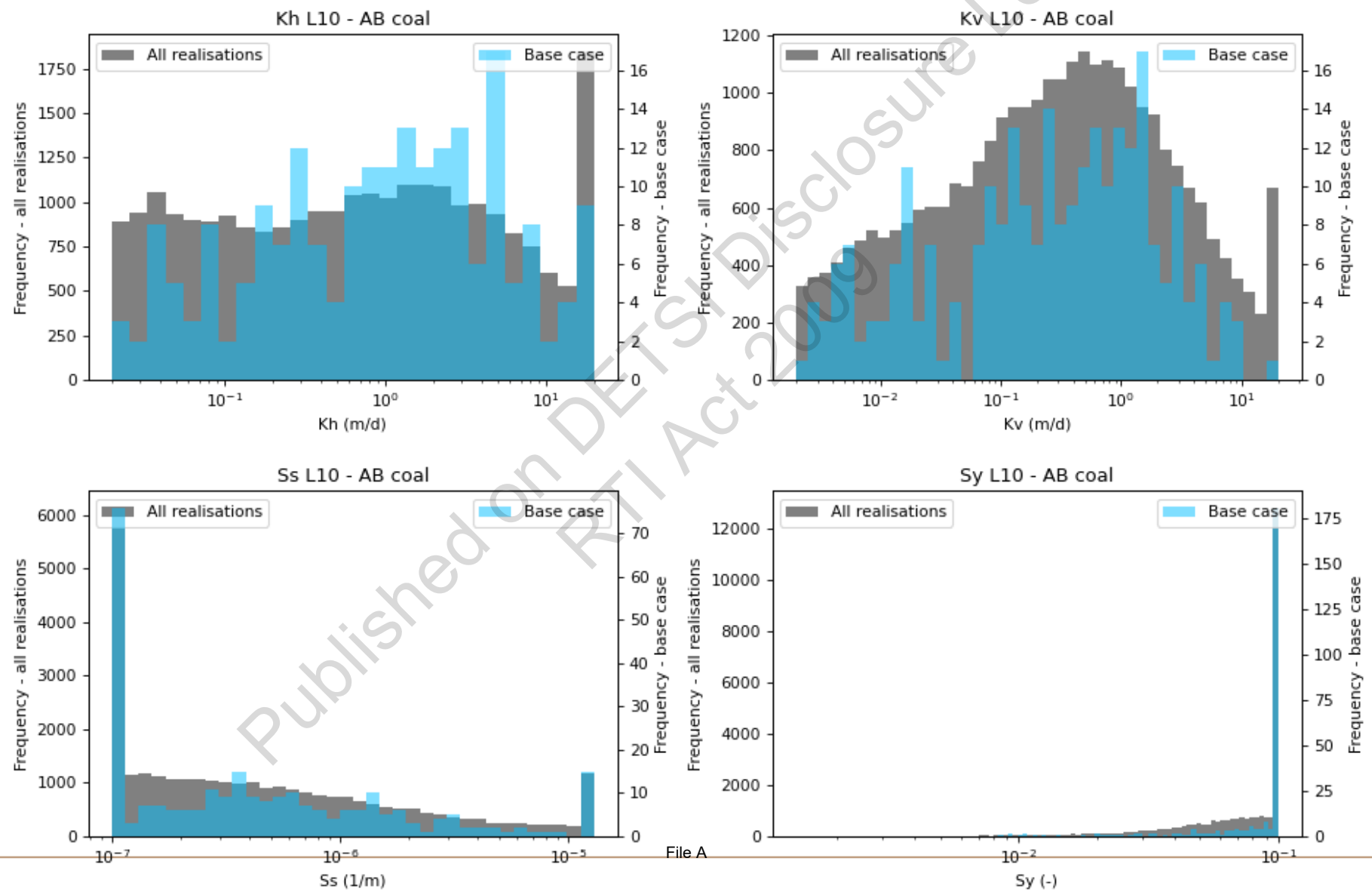
Parameterisation – L8 Rewan (lower)



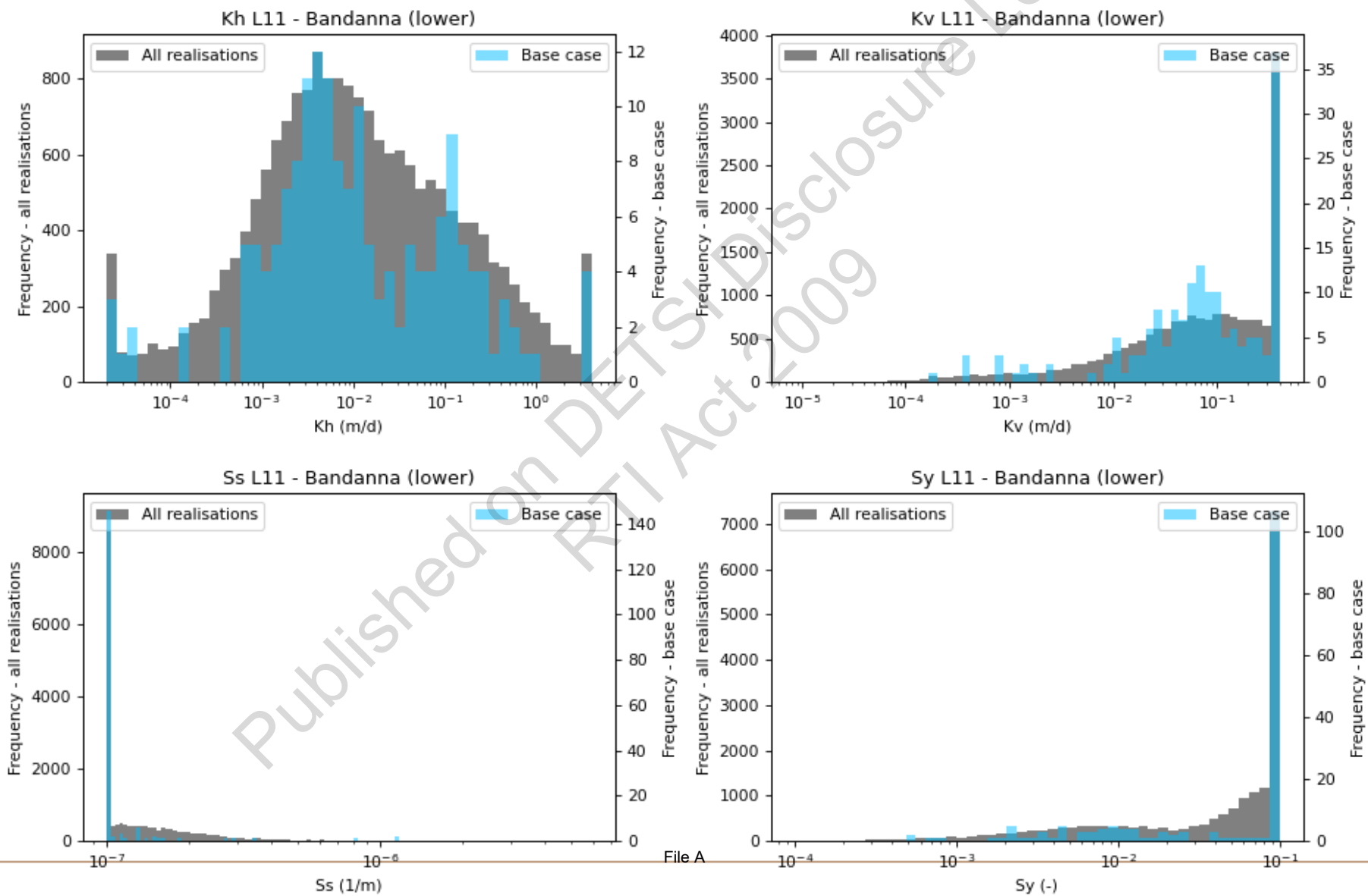
Parameterisation – L9 Bandanna (upper)



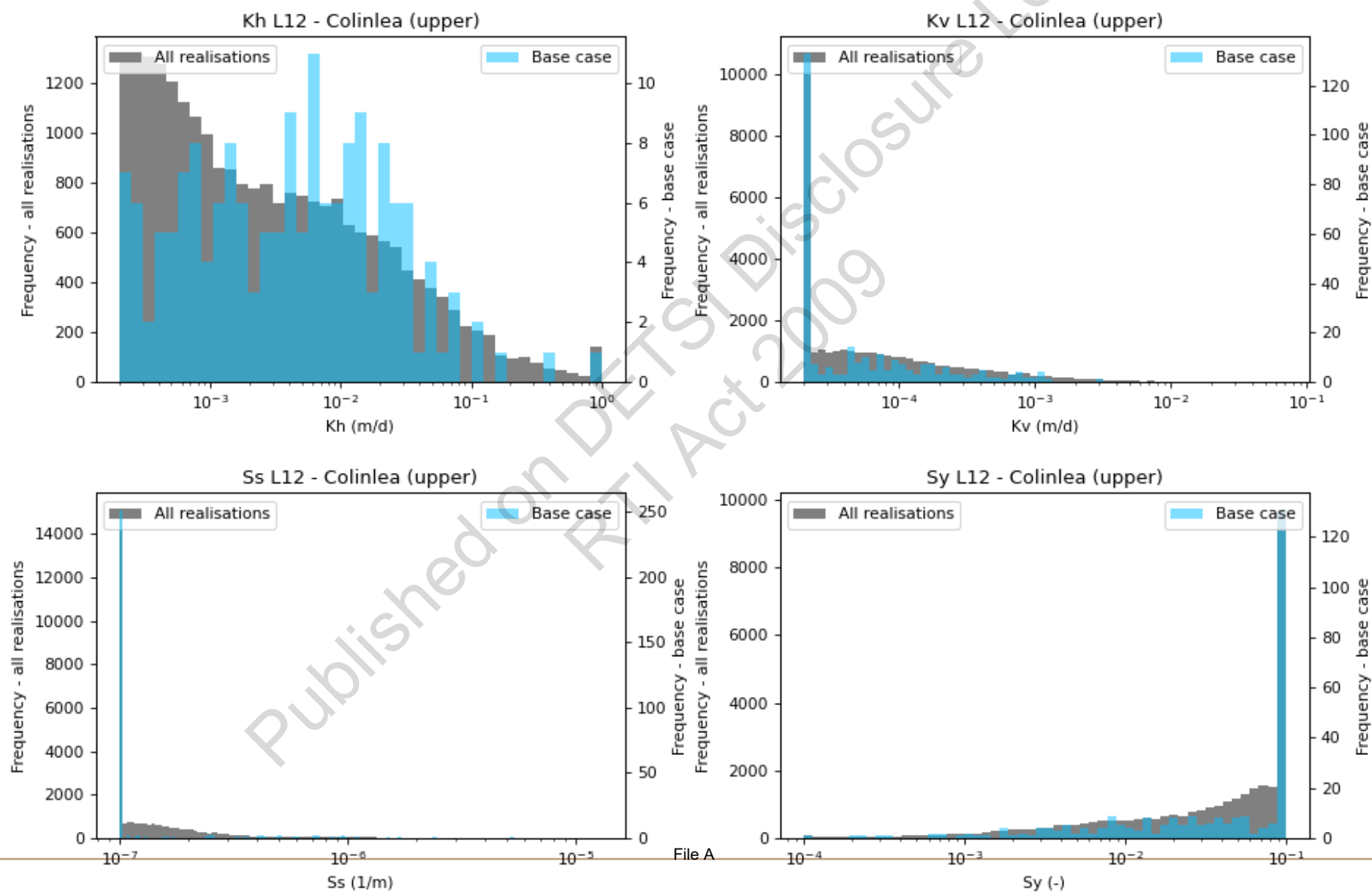
Parameterisation – L10 AB Coal



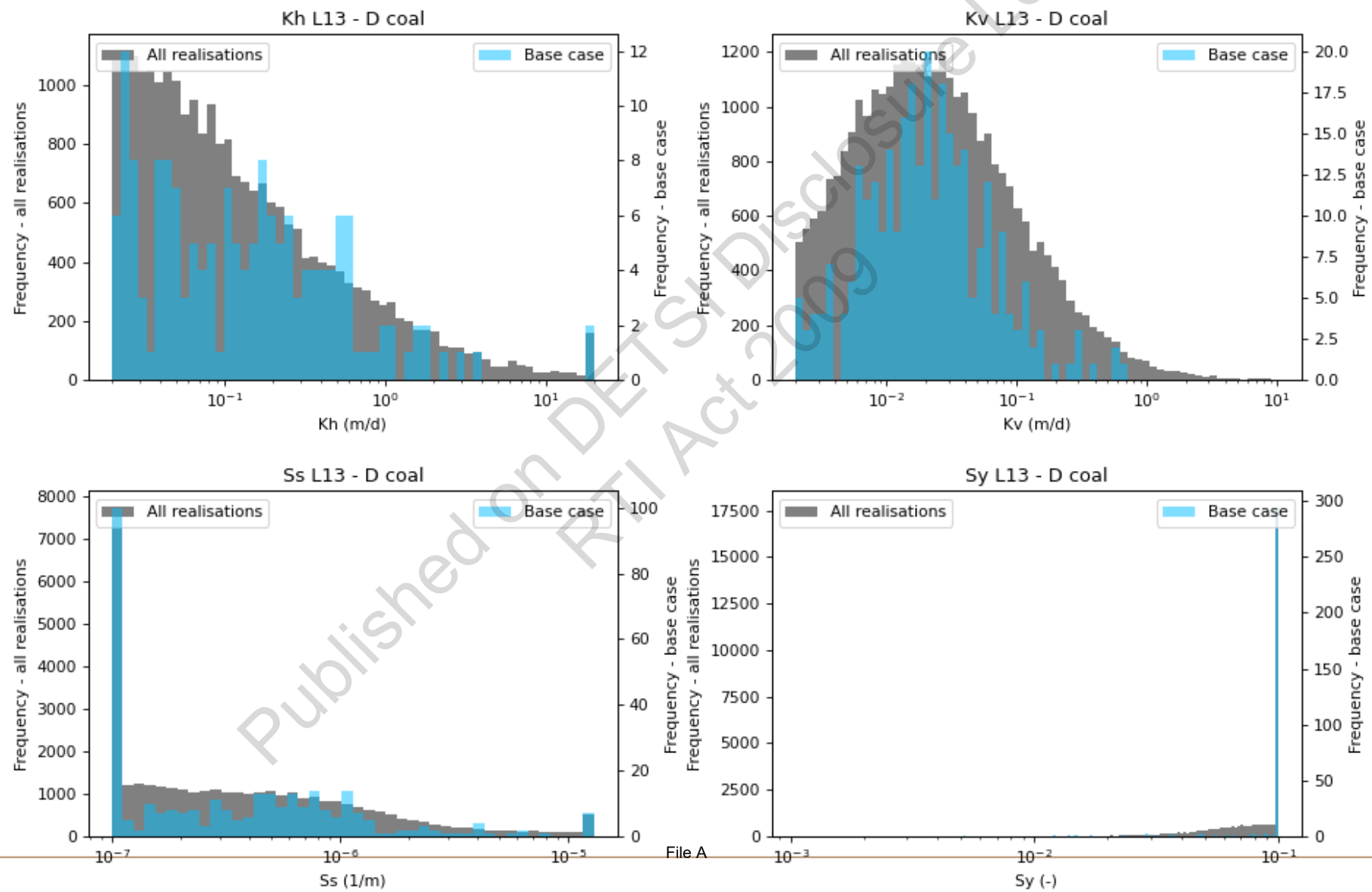
Parameterisation – L11 Bandanna (lower)



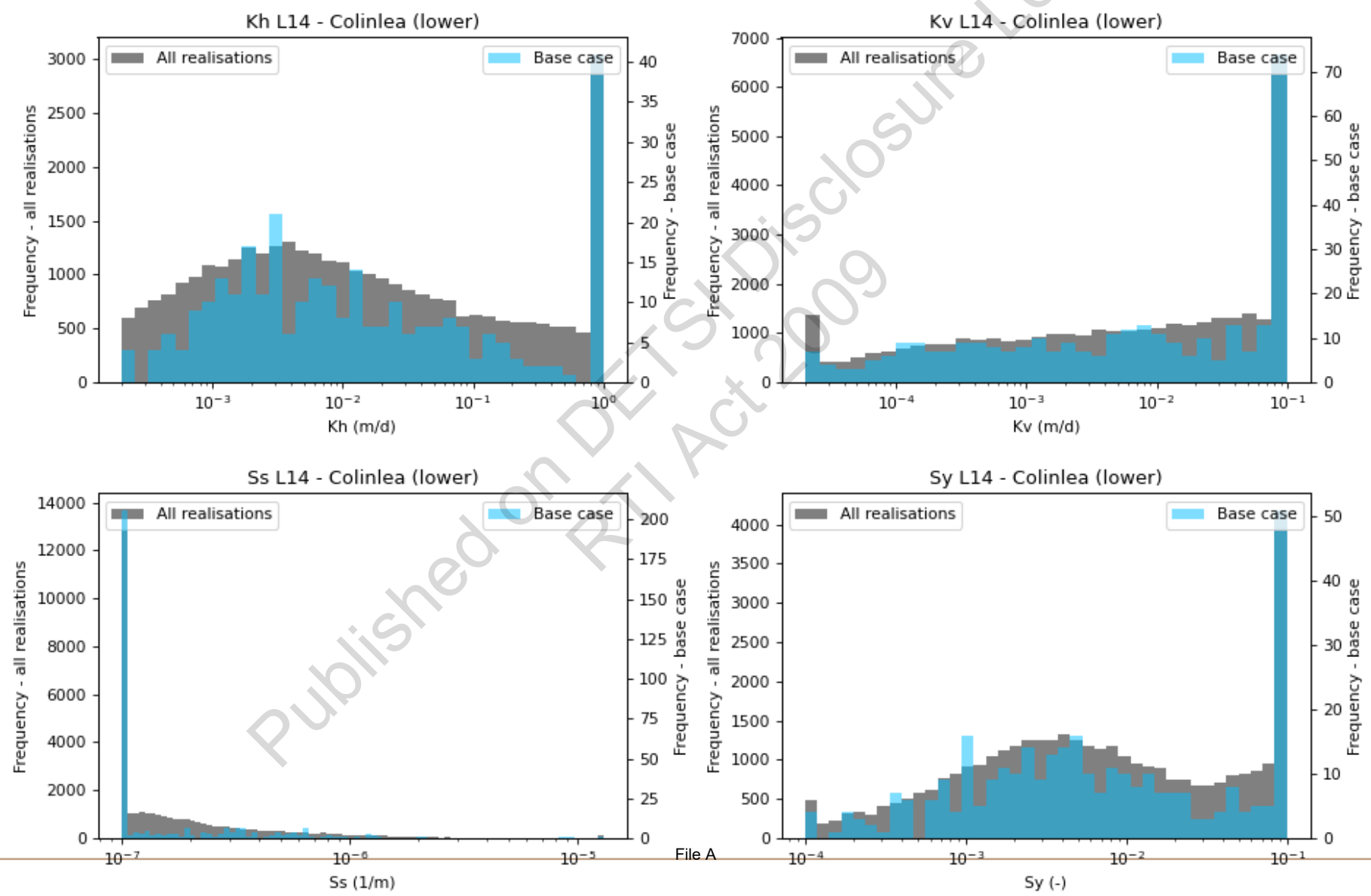
Parameterisation – L12 Colinlea (upper)



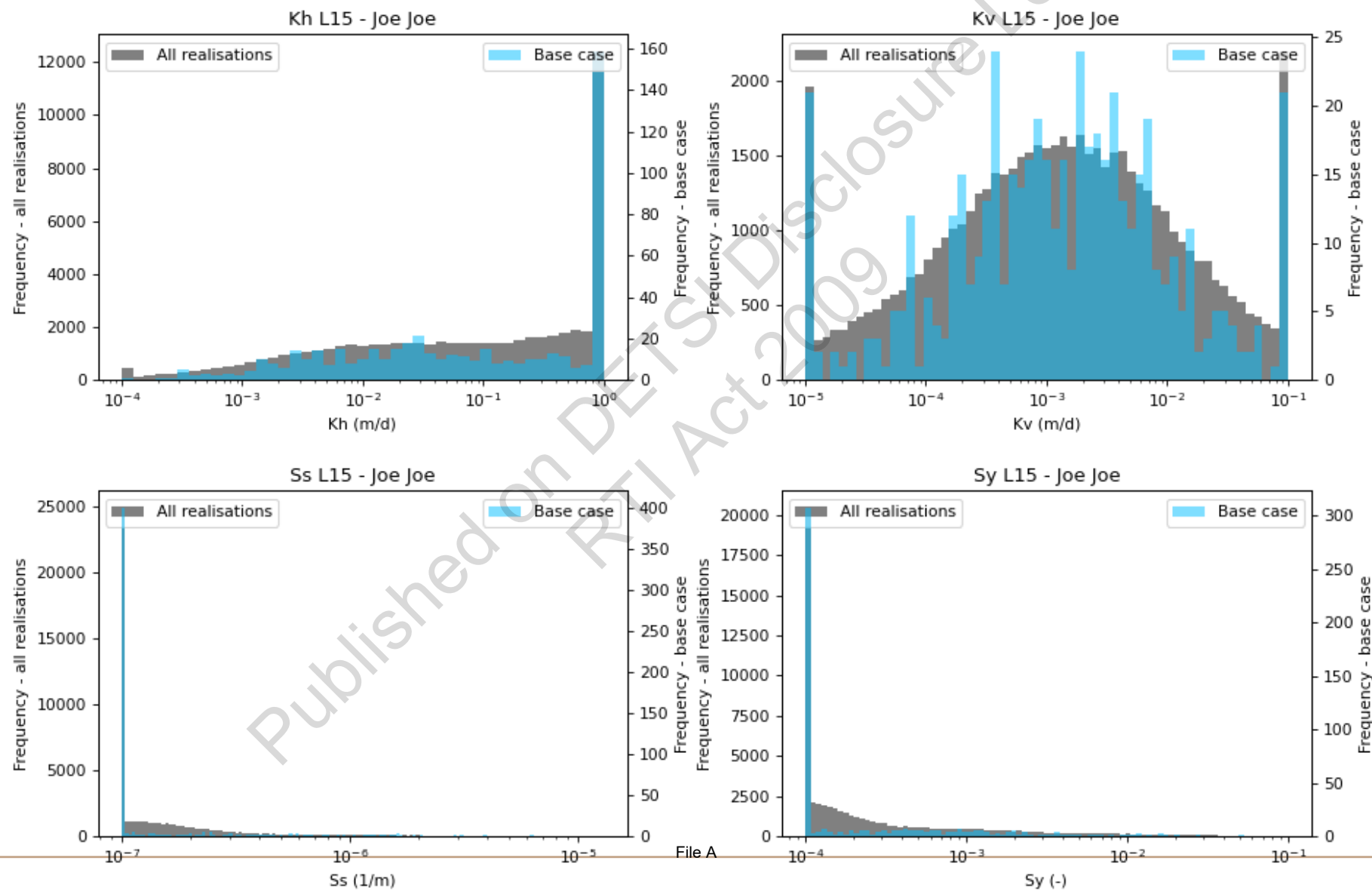
Parameterisation – L13 D Coal



Parameterisation – L14 Colinlea (lower)

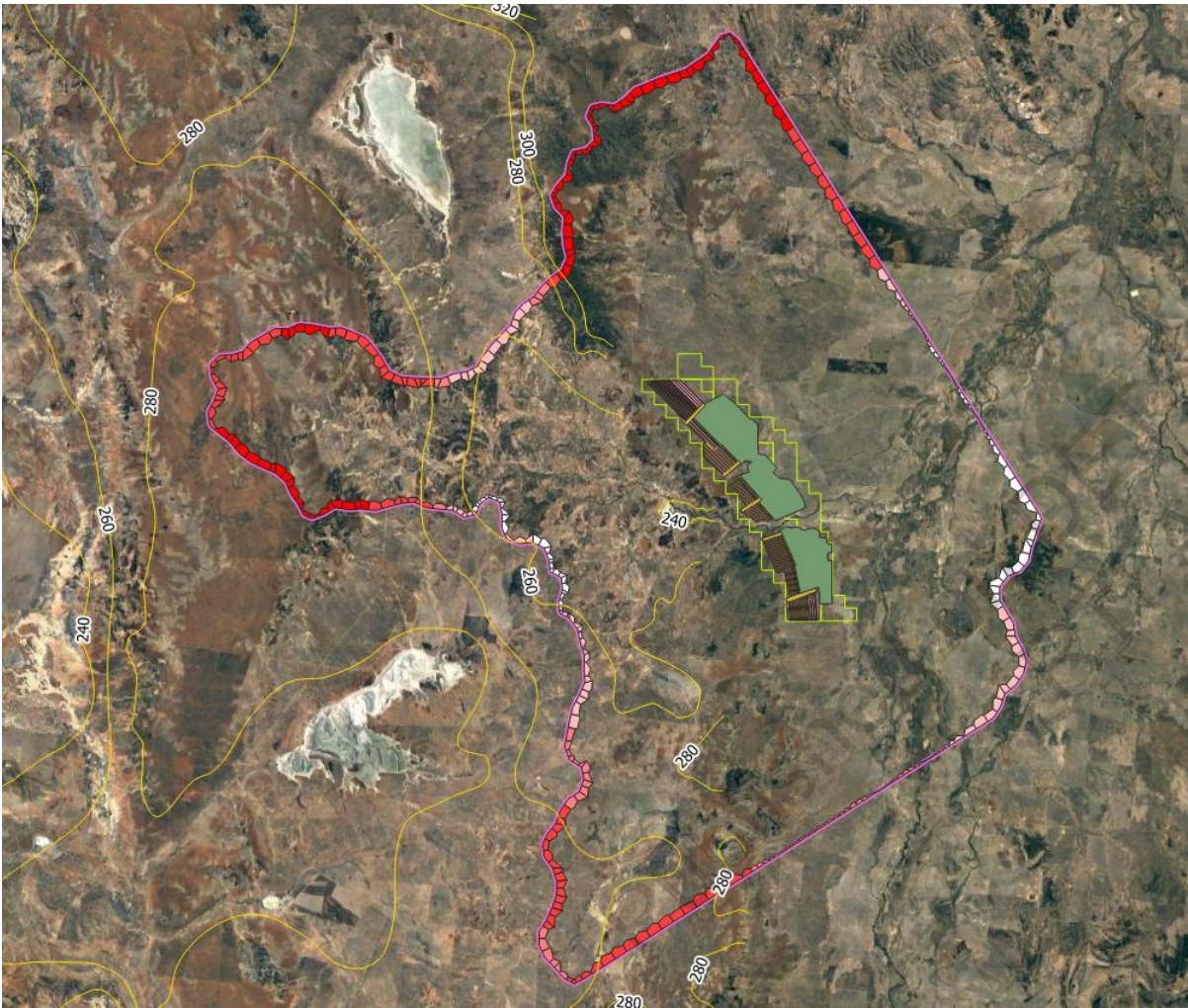


Parameterisation – L15 Joe Joe

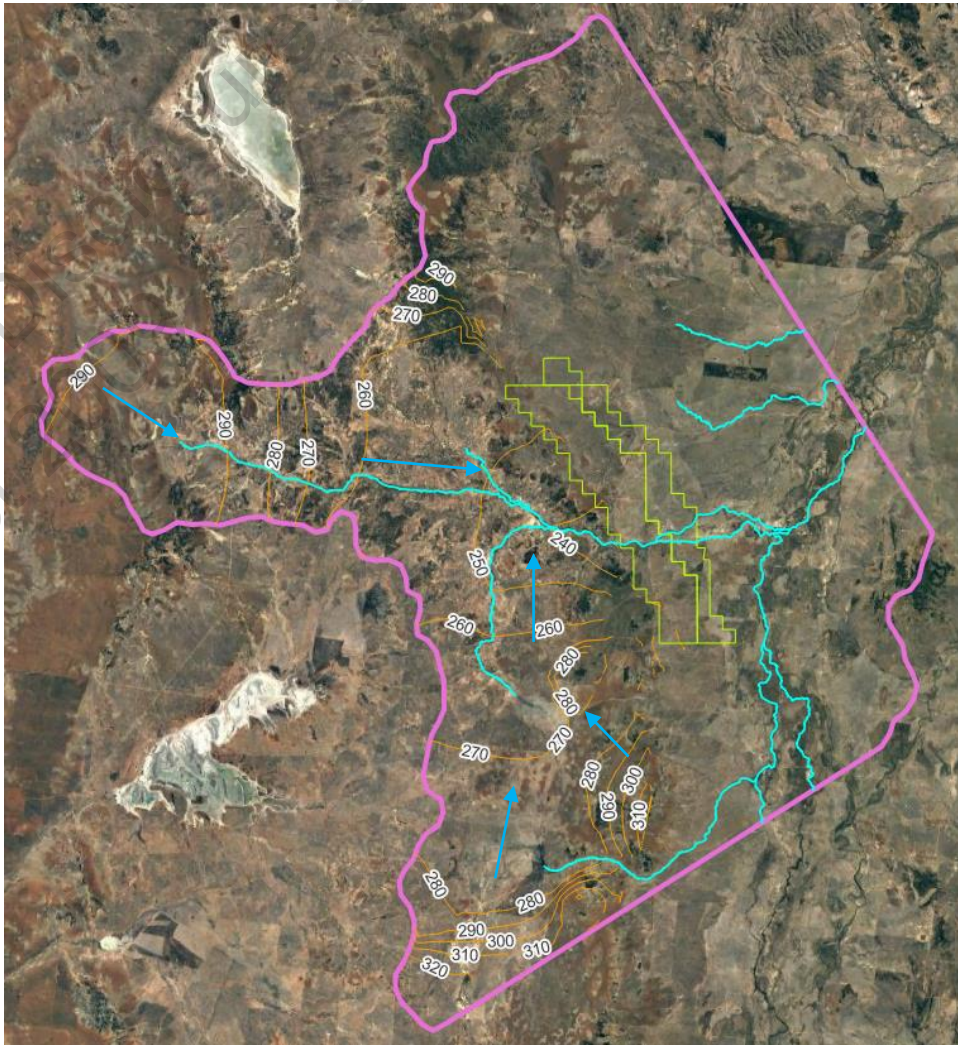


Steady state potentiometric surface – Clematis Sandstone

Interpreted

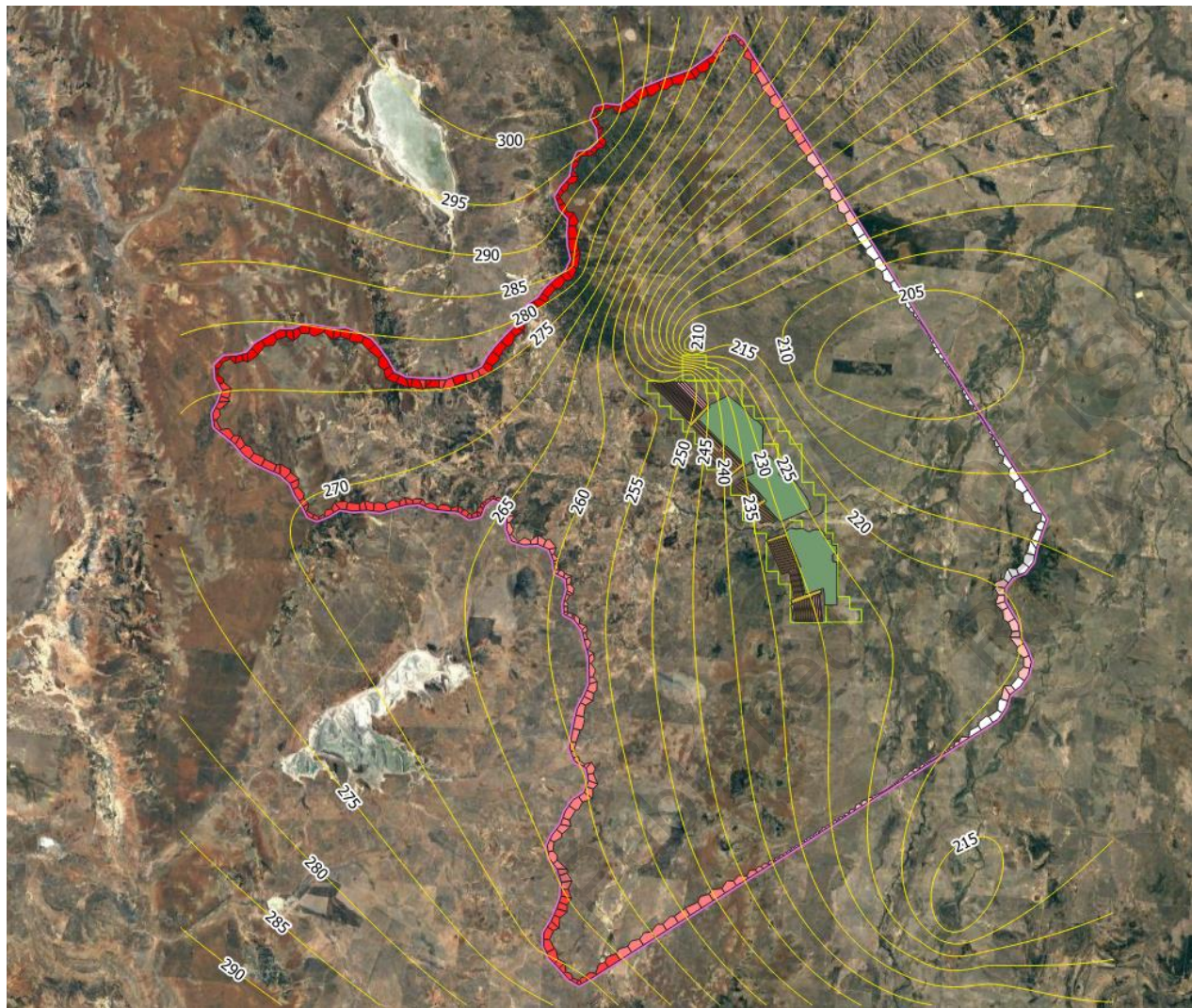


Modelled



Steady state potentiometric surface – Joe Joe Group

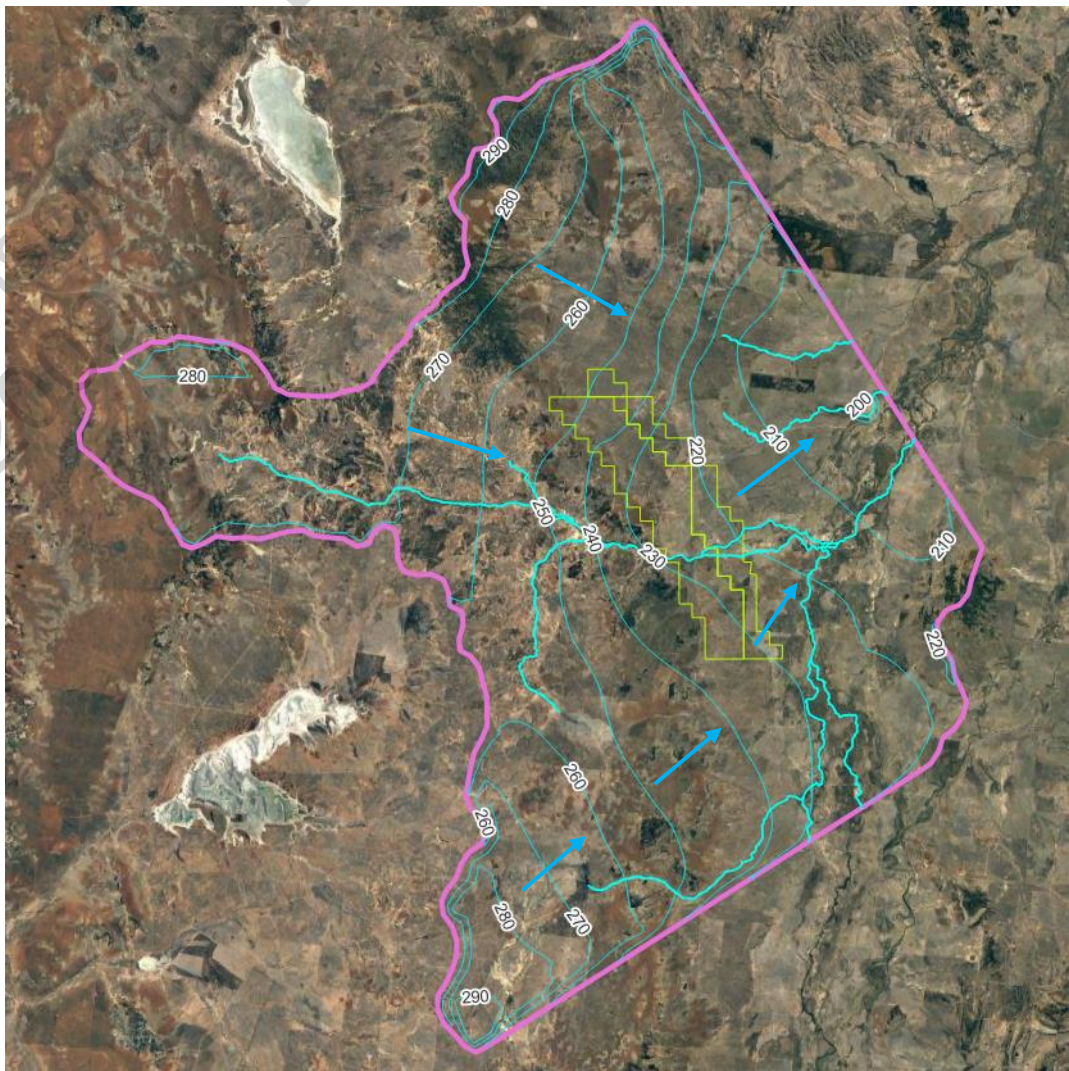
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22-312

File A

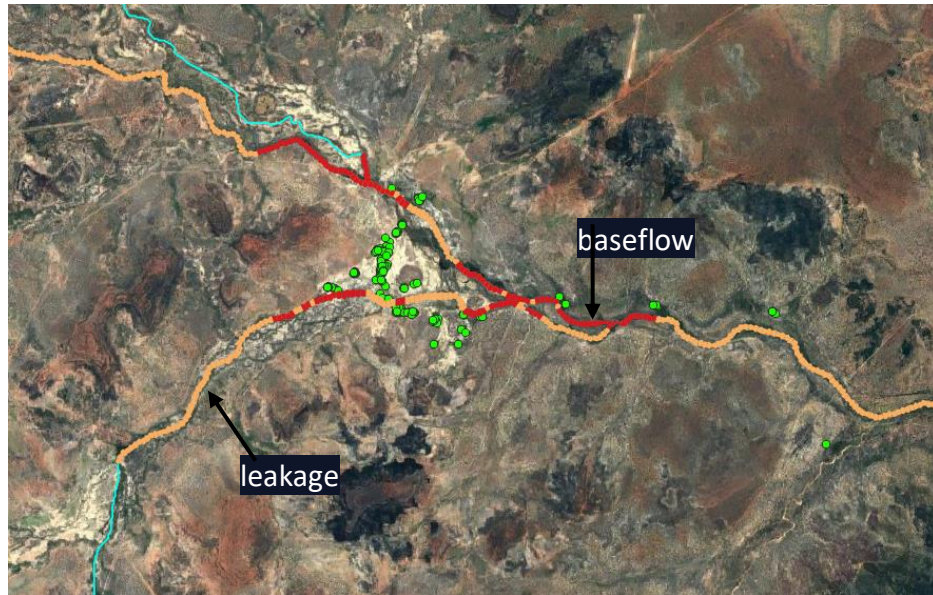
Modelled



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Surface water - groundwater interaction

End of wet season



End of dry season



- Upstream areas recharge groundwater system in the wet season
- Directly downstream of DSC, the Carmichael River is a gaining system all year round due to shallow groundwater levels and perhaps spring discharge
- Further downstream, Carmichael River becomes a losing system during the wet season and contributes no recharge during the dry season.
- The surface water system is mainly a losing system within the model domain

Steady state modelled water balance: base case

Modelled steady state water balance		
	Inflow (ML/d)	Outflow (ML/d)
Regional throughflow	33.83	25.60
Rainfall-derived recharge	0.69	-
Evapotranspiration	-	21.72
River baseflow/leakage	14.70	1.89
Spring discharge	1.19	1.17
Storage	-	-
TOTAL	50.40	50.40
IN-OUT		0.00
Mass balance error		0.01%

BRAVUS

MINING & RESOURCES

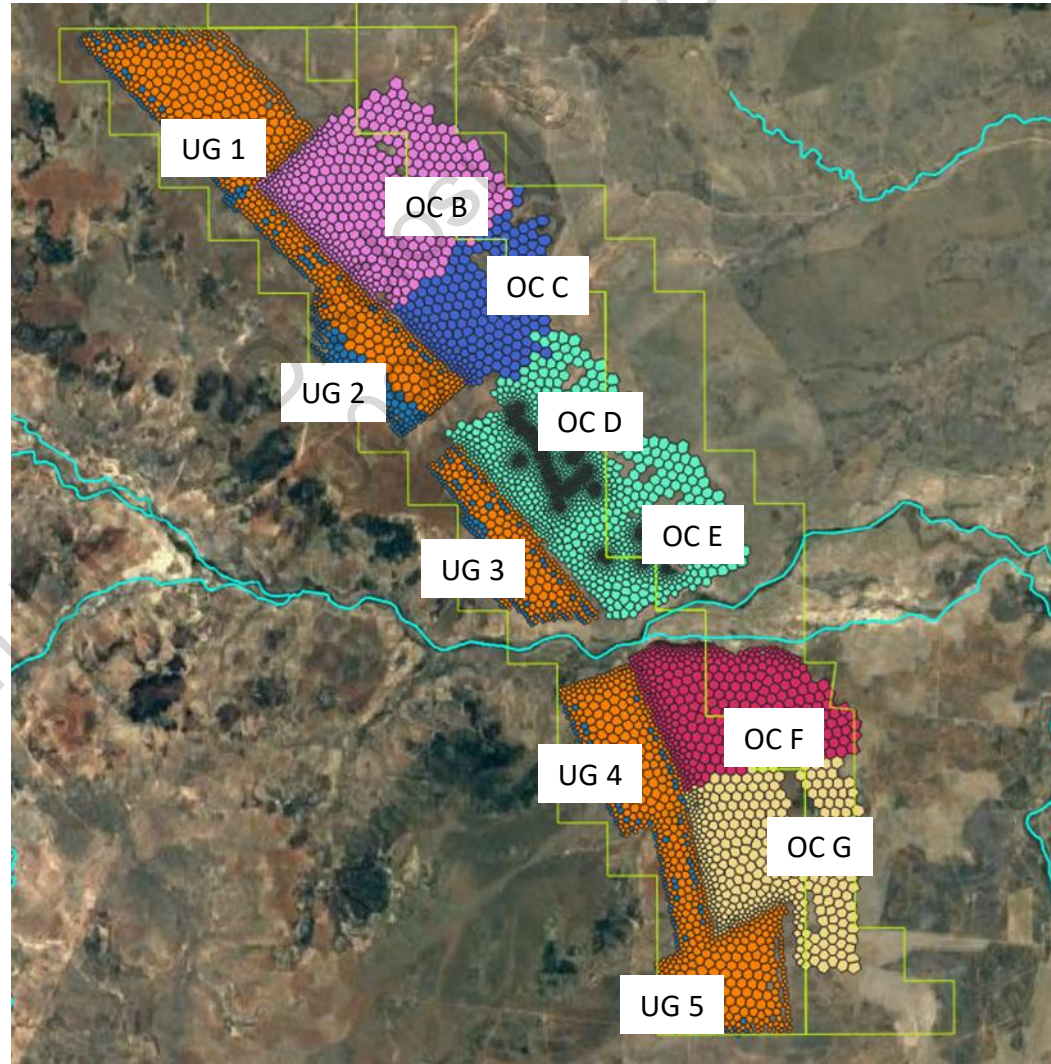
Predictive scenarios

Predictive scenarios

- OC: open cut mine only; no underground mining
- SEIS A: mine plan and fracturing as per SEIS (2013); full underground mine footprint
- SEIS B: mine plan as per SEIS (2013), fracturing geometry, relief zone and properties from Rewan research program
- Predictive scenarios include:
 - Drain boundary conditions representing mine plan, with stage at base of mine and high conductance to ensure full dewatering
 - Time-varying material properties above underground mine panels
 - SEIS A: horizontal and vertical hydraulic conductivity increased by a factor of 50 for first 75 m, then factor of 10 for remaining 75 m, no fracturing above Rewan. SEIS (2013) used a constant height of fracturing of 160 m above longwall panels.
 - SEIS B: horizontal and vertical hydraulic conductivity increased within 250 m above coal seam; log hydraulic conductivity reduction with height (ramp function, Merrick 2017)
 - Time-varying material properties in open cut mine model cells above AB Coal seam
 - Horizontal and vertical hydraulic conductivity increased to 1,000 m/d
 - Specific yield increased to 100%
 - Time-varying material properties in open cut mine model cells below AB Coal seam (backfill)
 - Horizontal and vertical hydraulic conductivity increased to 0.5 m/d
 - Post-mining recovery:
 - 2,000-year post-mining stress period
 - All dewatering deactivated but open cut pit, backfill and fracturing properties remain active

Modelled mine plan

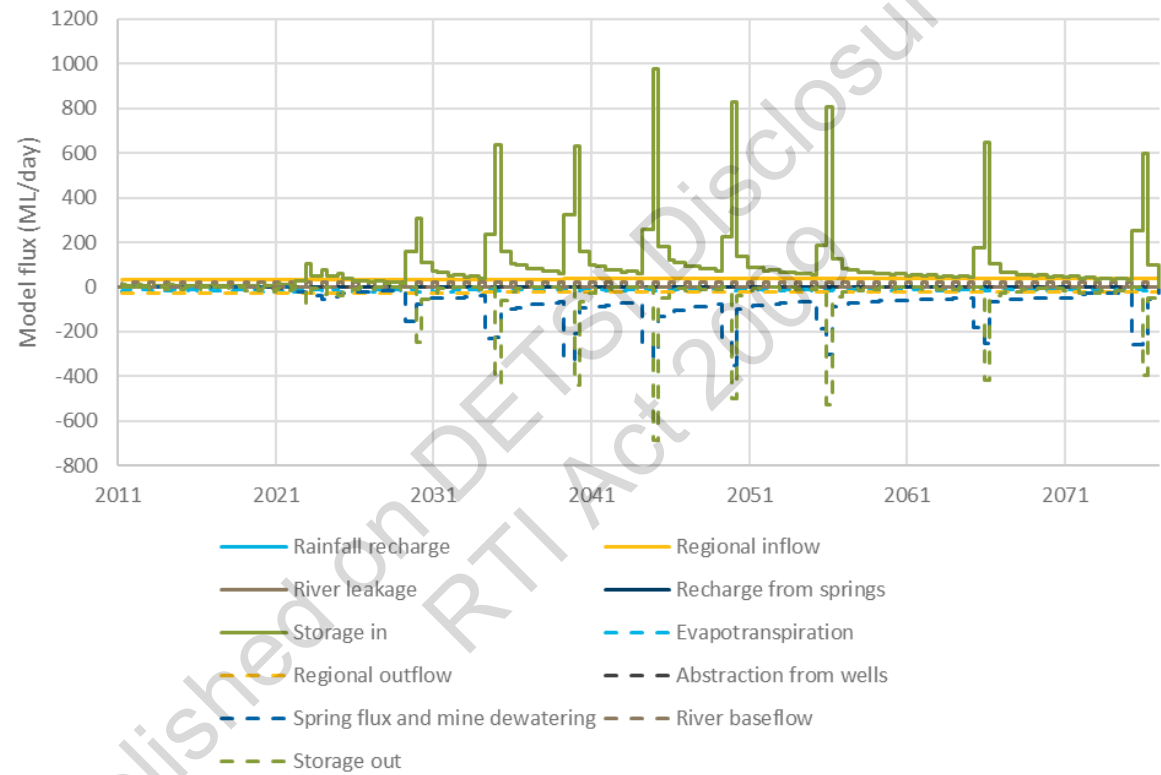
- OC: open cut
- SEIS: open cut and underground



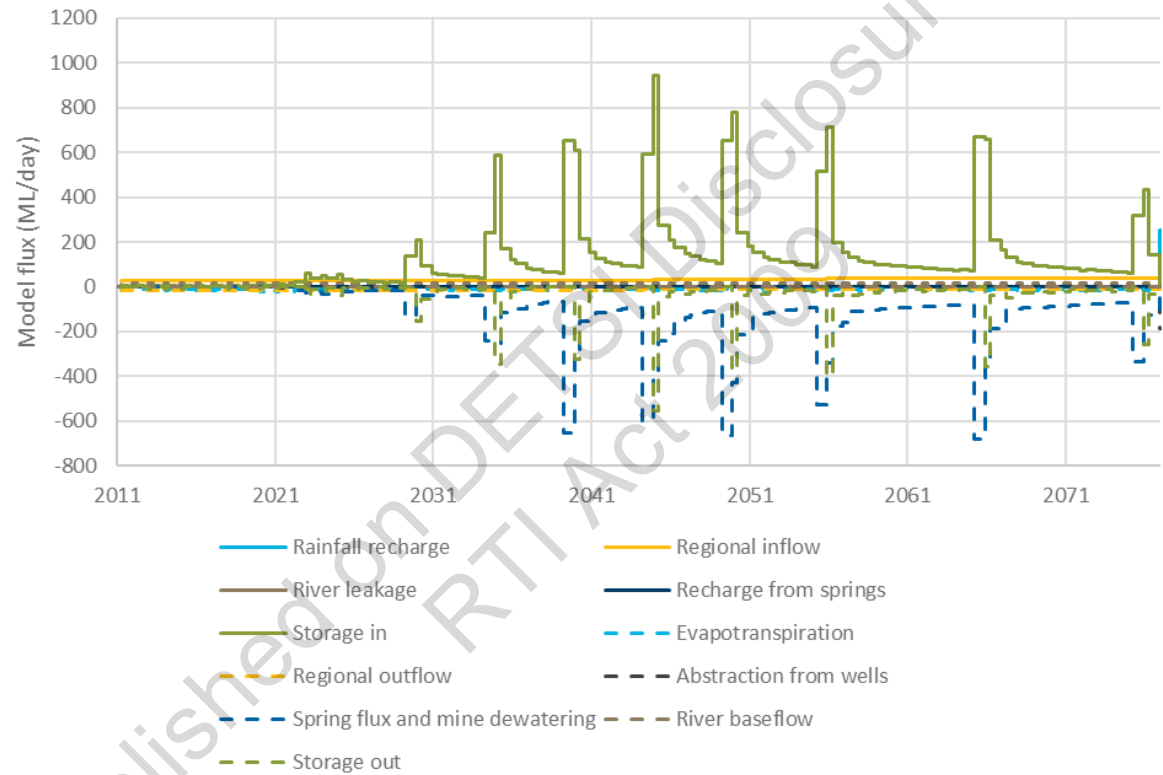
Modelled mine plan (as per SEIS)

Year	OC B	OC C	OC DE	OC F	OC G	UG 1	UG 2	UG 3	UG 4	UG 5
2020			Active							
2021			Active							
2022			Active							
2023			Active							
2024			Active							
2029		Active	Active							
2034	Active	Active	Active			Active				
2039	Active	Active	Active	Active	Active					
2044	Active	Active	Active	Active	Active				Active	Active
2049	Active	Active	Active	Active	Active					
2055	Active	Active	Active	Active	Active			Active		
2065	Active	Active	Active	Active	Active		Active			
2075	Active			Active	Active					

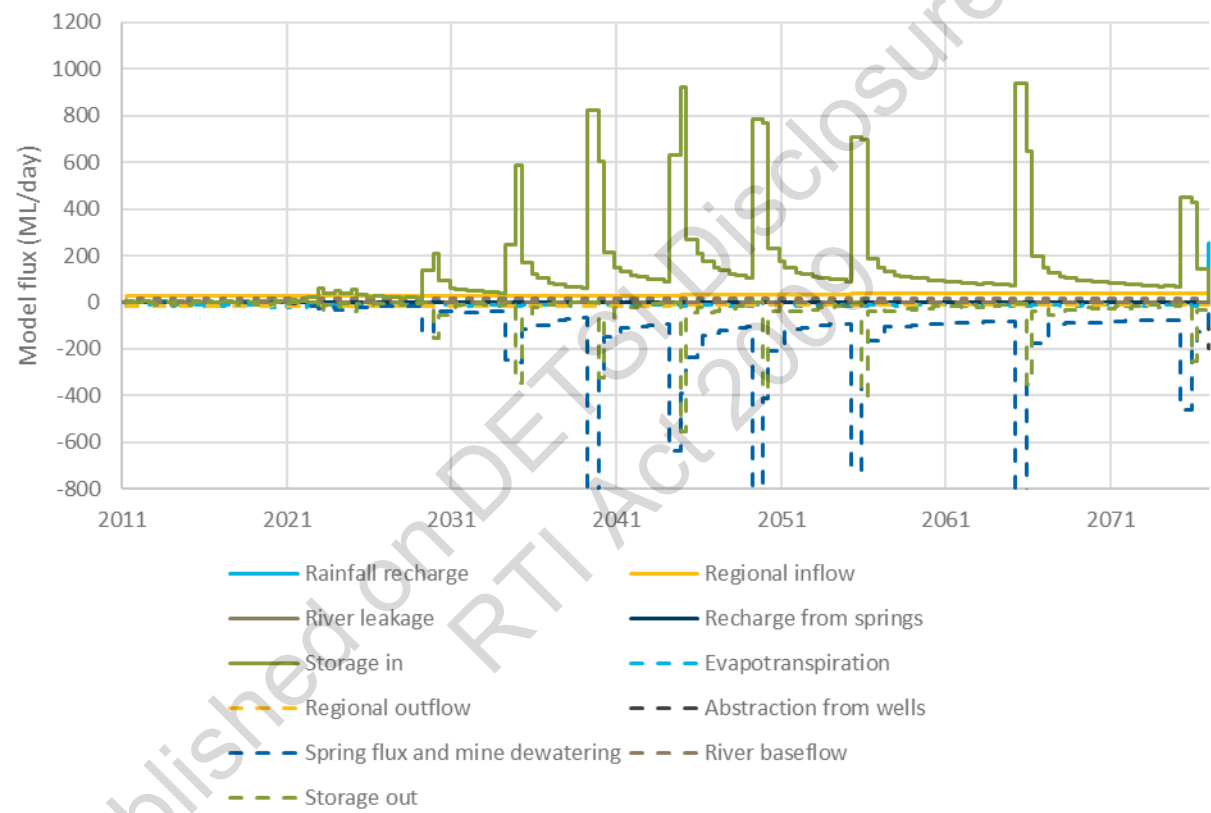
Modelled water balance: OC



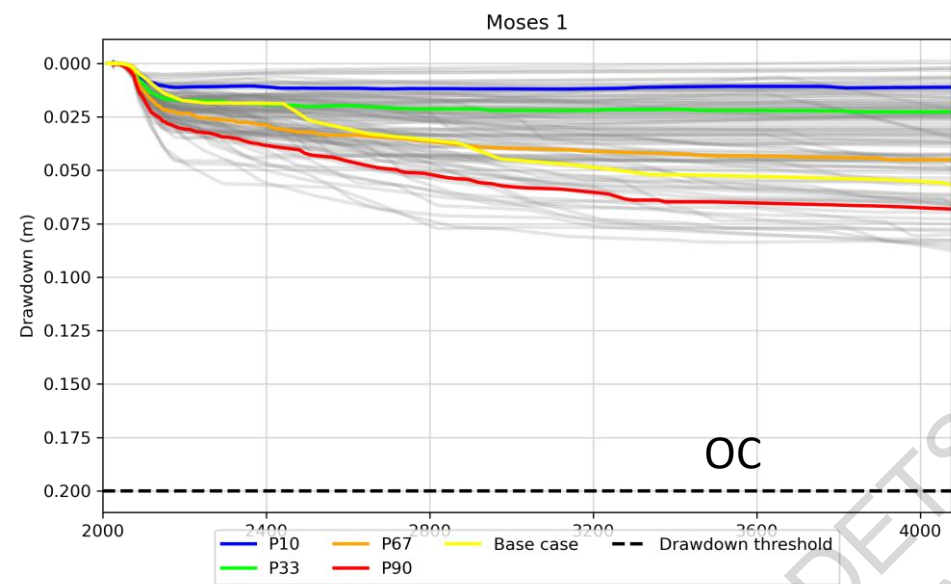
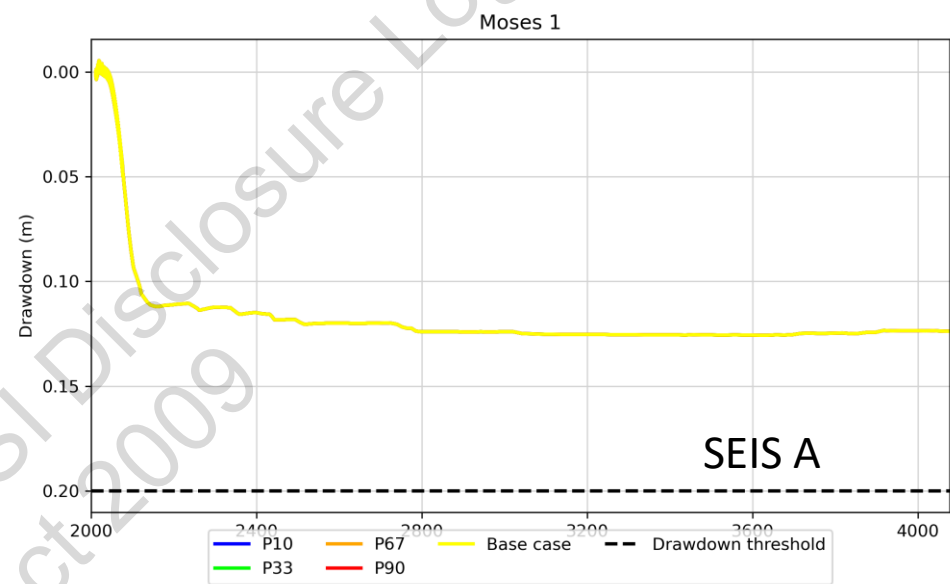
Modelled water balance: SEIS A



Modelled water balance: SEIS B



Modelled hydrographs



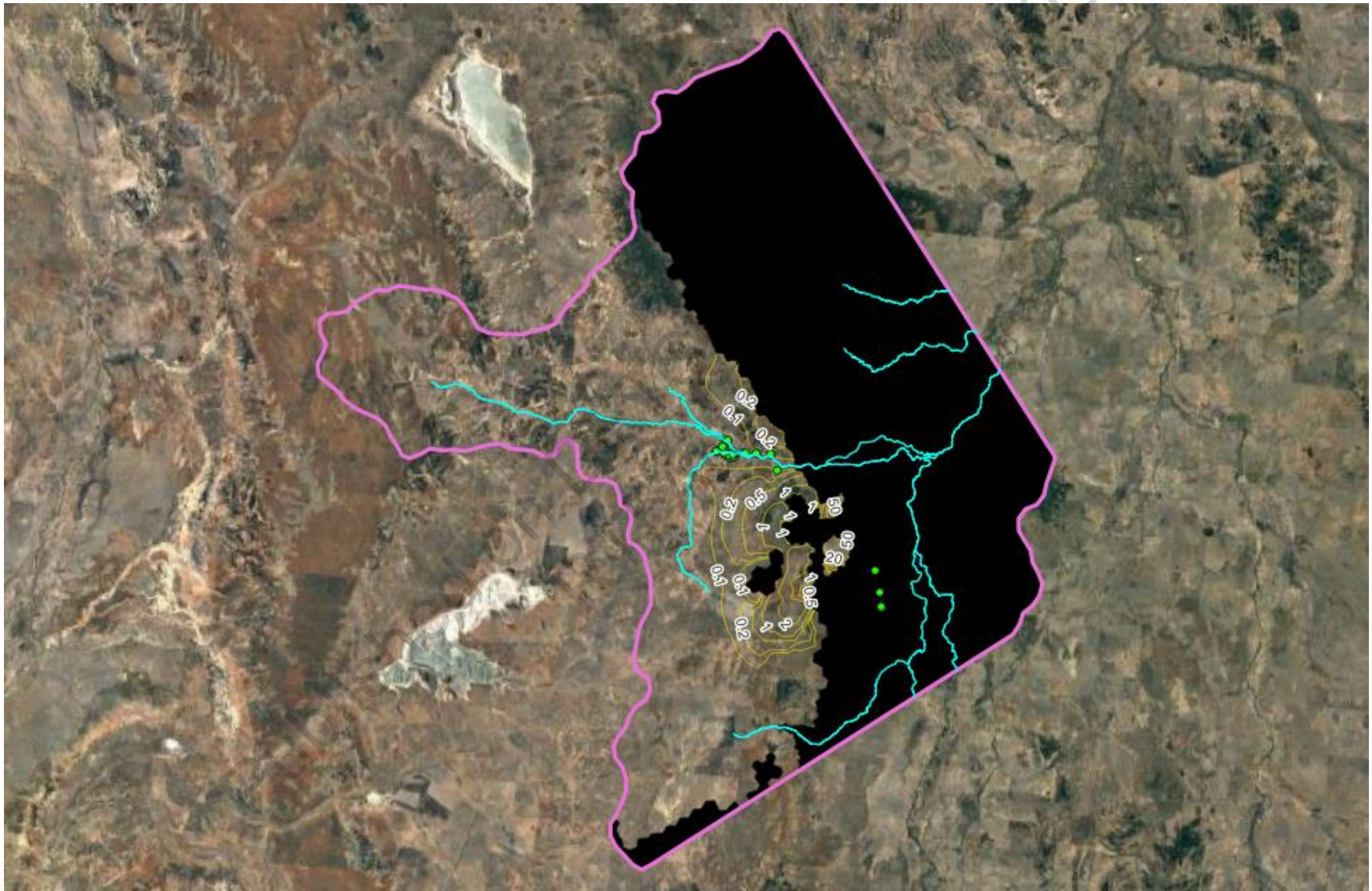
Modelled drawdown (m) at springs

Spring	GHD (2013)	OC	SEIS A	SEIS B
Moses 4	<0.05	0.05	0.12	0.31
Moses 3	<0.05	0.05	0.12	0.31
Moses 2	0.08	0.05	0.12	0.31
Little Moses 1	<0.05	0.05	0.08	0.24
Moses 1	0.06	0.06	0.13	0.32
Moses 7	0.09	0.05	0.12	0.31
Moses 10	0.08	0.05	0.12	0.31
Moses 15	0.07	0.05	0.12	0.31
Moses 20	0.12	0.06	0.12	0.31
Moses 26	0.12	0.06	0.12	0.31
Joshua Spring	0.19	0.02	0.03	0.13
Mellaluka 1	<0.05 – 1.03	>10	>10	>10
Mellaluka 2	<0.05 – 1.14	>10	>10	>10
Storys	<0.05 – 2.34	>10	>10	>10
Lignum	0.06 – 8.22	>10	>10	>10

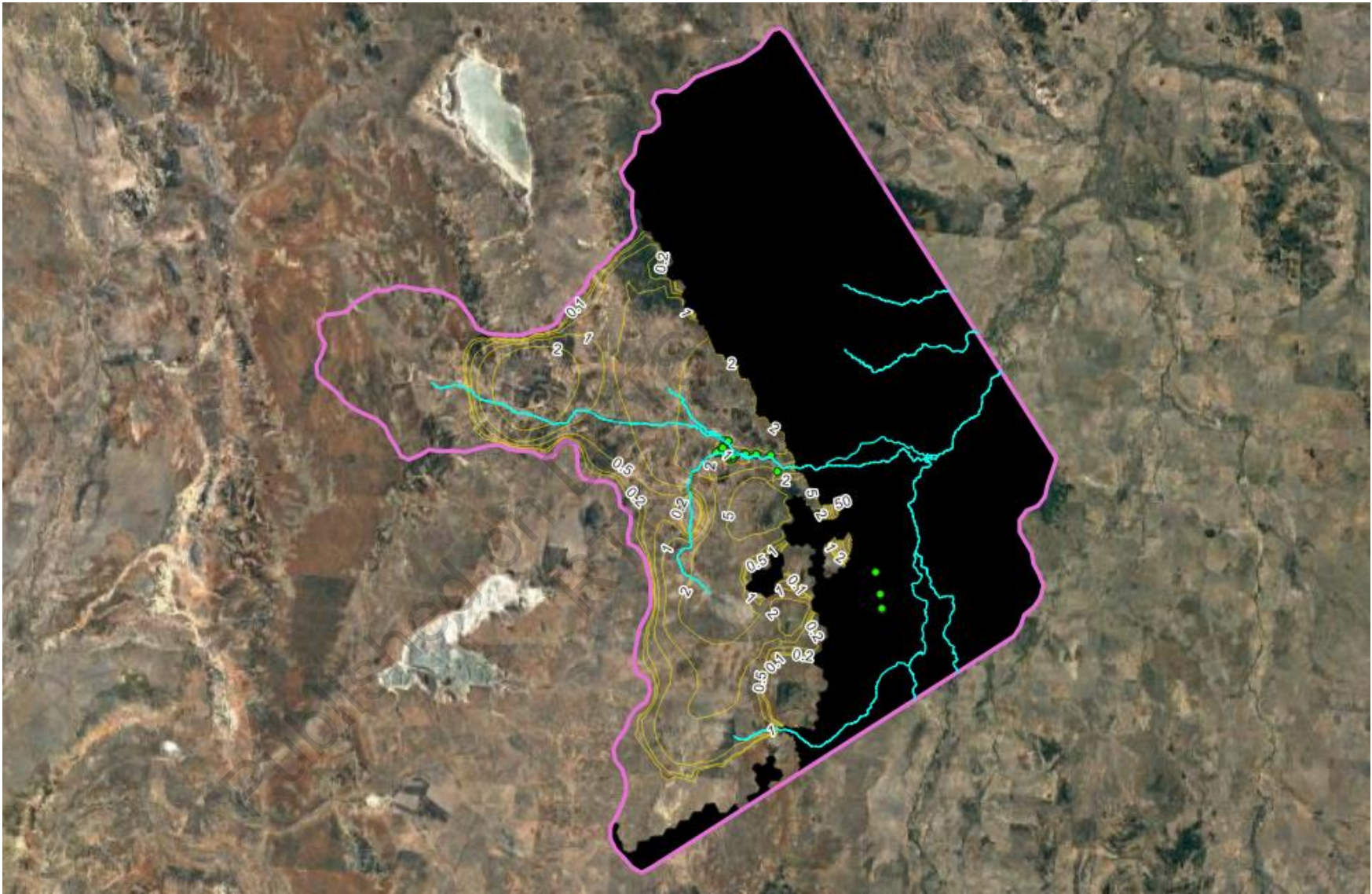
Proportion of runs exceeding 0.2 m drawdown at DSC for open cut only scenario

Spring	OC
Moses 4	0%
Moses 3	0%
Moses 2	0%
Little Moses 1	0%
Moses 1	0%
Moses 7	0%
Moses 10	0%
Moses 15	0%
Moses 20	0%
Moses 26	0%
Joshua Spring	0%

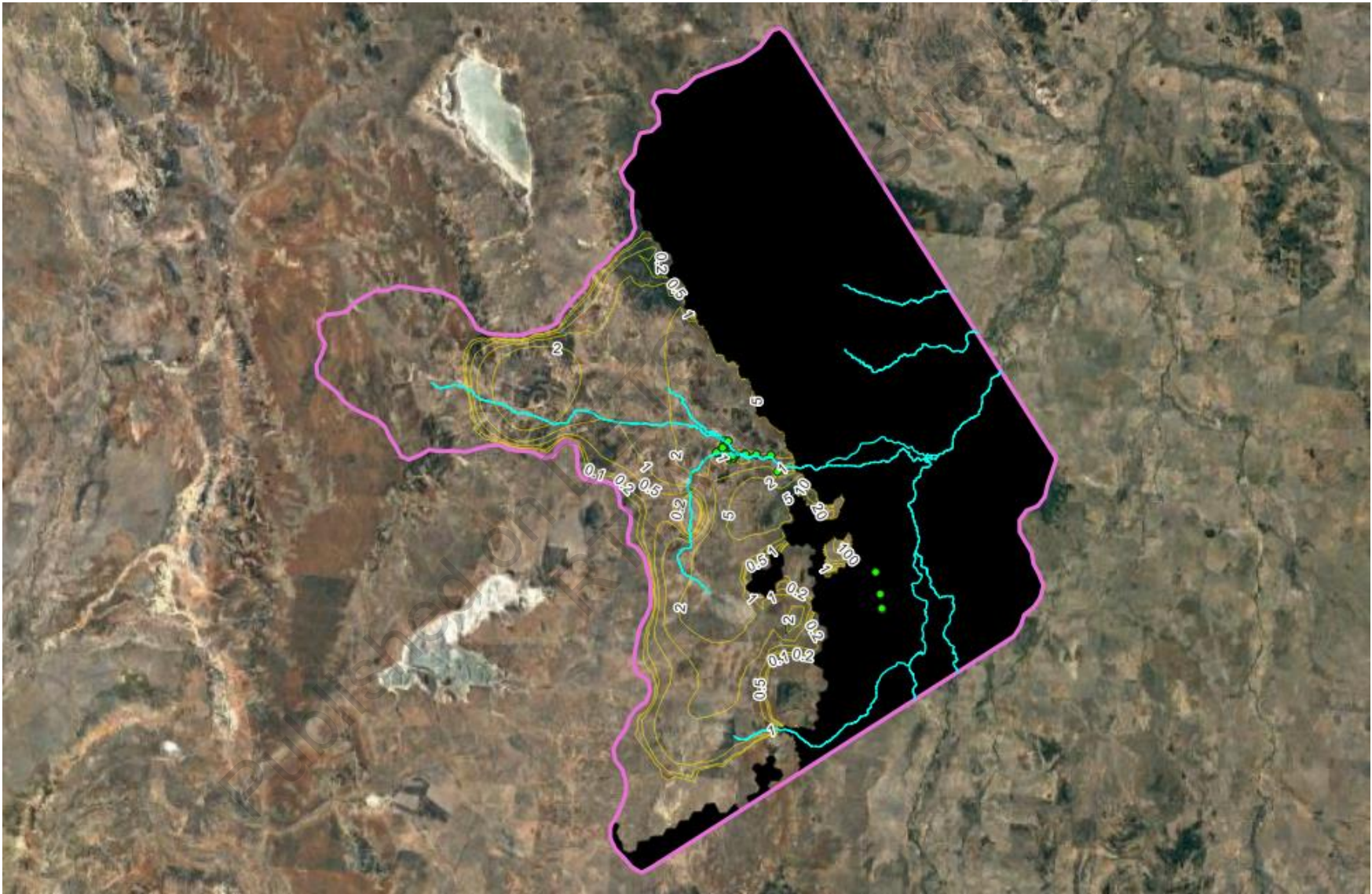
Modelled base case drawdown in Clematis: OC



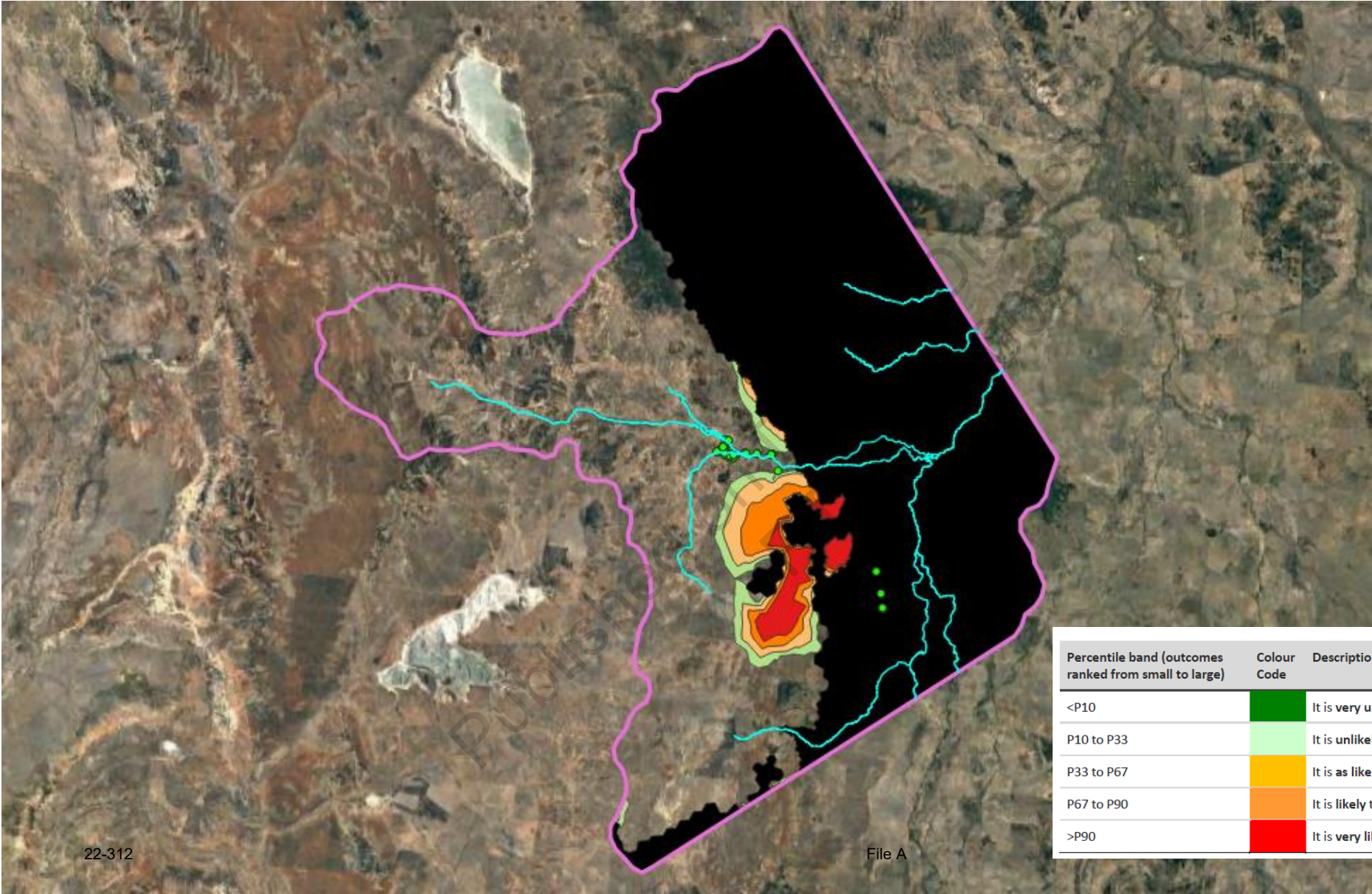
Modelled base case drawdown in Clematis: SEIS A



Modelled base case drawdown in Clematis: SEIS B



Likelihood of 0.2 m drawdown exceedance in Clematis: OC



- Presented drawdown is maximum regardless of timing
- Results presentation aligns with IESC 2018 explanatory note (Middlemis & Peeters)

Percentile band (outcomes ranked from small to large)	Colour Code	Description of likelihood
<P10	Dark Green	It is very unlikely that the drawdown/mounding exceeds the threshold
P10 to P33	Light Green	It is unlikely the drawdown/mounding exceeds the threshold
P33 to P67	Yellow	It is as likely as not the drawdown/mounding exceeds the threshold
P67 to P90	Orange	It is likely the drawdown/mounding exceeds the threshold
>P90	Red	It is very likely the drawdown/mounding exceeds the threshold

Summary

- Model updated to meet Environmental Authority (EA) Condition E9, while addressing past review criticisms of the SEIS.
- Model rebuilt aligned with updated conceptualisation and datasets including geological model, groundwater pressures, groundwater drawdown and mine dewatering bore rates. Knowledge from Rewan Research and GAB Spring Research packages (i.e. spring conceptualisation and discharge volumes) incorporated.
- As noted by T Murray (2022), tying in the local Rewan Research model to the Bioregional assessment model highlighted some very significant mismatches and worrying errors. Murray recommended that a full review of the broader Bio-regional assessment model is warranted.*
- Model history-matching and predictive uncertainty analysis used pilot points and PESTPP-IES with 500 parameter realisations developed.
- Results predict that the open cut (OC) only scenario will not breach the DSC drawdown threshold of 0.2 m for the base case or majority of ensemble of realisations.
- Although the OC basecase and the majority of realisations do not breach DSC drawdown thresholds, significant modelled drawdown emanates from the OC F and G pits. This is caused by the assumption that Clematis Sandstone exists in this region.*

Summary

- Modelling of the SEIS mine plan using the previous model fracturing assumptions (Scenario A) associated with underground mining, results in base case drawdowns that do not breach the DSC 0.2 m drawdown threshold. These are comparable to the SEIS (2013) model results.
- Modelling of the SEIS mine plan using updated fracturing and relief zone assumptions (Scenario B), results in base case drawdowns that do breach the 0.2 m drawdown threshold, but only in the order of 5-10 cm.

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Recommendations

- The groundwater system is complex, with vertical hydraulic gradients evident within the Clematis Sandstone. Further refinement to model layering within this unit may be required in future.
- Drawdown in the Clematis is exacerbated in the southern area of the mine, largely due to the interpreted/assumed geological layering. Further drilling is recommended to confirm the geology in this area (outcrop/subcrop, thickness and extent).
- Based on drilling outcomes, further Clematis, Bandanna and/or Colinlea monitoring bores may be required in the southern region to monitor drawdown impacts, which potentially could emanate from OC F and G pits. This is in addition to previously recommended bores to be installed in the western portion of the mining lease, east of the DSC.*
- The model tends to simulate hydraulic heads higher than measured in regional discharge areas (i.e. heads <220 mAHD). Further investigation into this may be warranted to identify whether this is a regional throughflow process or whether groundwater may be discharging at greater rates within the model domain (e.g. greater evapotranspiration).
- A large amount of uncertainty remains associated with fracturing above and relief zone around, underground mining areas. Predictions appear to be sensitive to how these are simulated but, to date, there are no site data available to inform how the local system behaves. Updated knowledge, where available, should be used within the next 5-year model review with accompanied future predictive uncertainty analysis.

Recommendations

- Due to the current uncertainty associated with fracturing above and relief zone around, underground mining areas, it recommended that GMMP develops groundwater drawdown thresholds that are associated with the OC mining scenario only, at this stage.*
- Future GAB Spring Research studies will concentrate on ecological water requirements (EWRs) of springs. Future modelling should include updated EWRs and associated thresholds.

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Discussion



Carmichael Coal Mine: RP1.6 Hydrogeological conceptualisation and updated groundwater modelling

Report No.2: Numerical groundwater flow model report

Prepared for Bravus Mining and Resources

January 2023

Executive Summary

Click here to begin typing. For headings in the Executive Summary please use Summary Heading 1-5 styles. These styles are located under the More Styles button on the EMM ribbon. This ensures correct structure of your TOC.

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1 Introduction

1.1 Project background

Bravus Mining and Resources (Bravus) has commenced development of the Carmichael Coal Mine (CCM) located in the Galilee Basin, approximately 160 kilometres (km) northwest of Clermont in Central Queensland. The Carmichael Coal Mine and Rail Project was assessed by the Commonwealth and Queensland governments through an Environmental Impact Statement (EIS) process. Conditional approval of the Carmichael Coal Mine and Rail Project was granted by the Queensland Coordinator-General on 8 May 2014 and the Commonwealth Minister for the Environment on 14 October 2015 (EPBC 2010/5736). The Environmental Authority (EA) EPML01470513 for the Mining Leases (ML) 70441, 70505 and 70506 was initially granted on 2 February 2016 and further amended in September 2019, July 2020 and most recently April 2022.

A numerical groundwater model has been developed in accordance with EA **Condition E9**. The condition requires the previous SEIS groundwater model first developed in 2013 to support the initial approvals, to be reviewed and updated where appropriate, allowing the GMMP to be updated in accordance with **Condition E4** and **Condition E5**. This update includes but not limited to: groundwater monitoring data, predicted mine dewatering volumes, predicted groundwater drawdown and impacts to the Groundwater Dependant Ecosystems (including spring complexes and Carmichael River alluvium).

Condition E9 specifically requires the groundwater model to be updated to include a transient calibration and include additional model layers for aquifers below the D seam of the Colinlea Sandstone, and in accordance with the GMMP. Specific requirements for E9 are outlined in 1.6.

In accordance with **Condition E9 requirement j)** and **Condition E10**, Australasian Groundwater and Environmental (AGE) Consultants has been engaged as the independent peer reviewer.

1.2 Previous modelling

Summarise previous modelling – versions, by whom ...

1.3 Modelling objectives

The objectives of the updated groundwater modelling are to:

- meet the specific requirements outlined by EA **Condition E9**;
- incorporate updated knowledge and conceptualisation of the groundwater system, including addressing past review comments;
- simulate the approved CCM groundwater-affecting activities, including mine development and dewatering operations and compare to the original SEIS model results;
- predict groundwater volumes intercepted as a result of mining activities;
- predict the extent and magnitude of groundwater drawdown induced by mining activities, particularly at key receptors;
- assess the predictive uncertainty related to impacts associate with mine dewatering and the resulting predicted groundwater drawdown; and
- predict the long-term state of the groundwater system post mining.

1.4 Modelling guidelines

The model design, history-matching, predictions and predictive uncertainty analysis have been developed consistent with current guidelines including:

- Barnett et al. (2012), Australian groundwater modelling guidelines, Waterlines report, National Water Commission, Canberra; and
- Middlemis & Peeters (2018), Information guidelines explanatory note: Uncertainty analysis – guidance for groundwater modelling within a risk management framework.

In addition, the modelling approach is aligned with the philosophies explored during the Groundwater Modelling Decision Support Initiative (GMDSI), an industry-funded project focused on improving the role groundwater modelling plays in environmental management and decision making.

1.5 Report structure

The structure of the report has been developed to logically step through the modelling process, and is structured as follows:

- Section 2 - A summary of the hydrogeological conceptualisation, recently updated by EMM and presented in detail within the Hydrogeological Conceptualisation Report (EMM 2022a);
- Section 3 - The model design outlining the approach to represent the conceptual model in a quantitative and numerical framework, while meeting the modelling objectives;
- Section 4 - History matching, which includes an approach to determining the basecase realisation along with a suite of alternative realisations;
- Section 5 - Basecase prediction and predictive uncertainty analysis- add more detail in final report;
- Section 6 - Approach to addressing past model review criticism- add more detail in final report; and
- Section 7 – Summary and recommendations- add more detail in final report.

Figure 1.1 Carmichael coal mine location map

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1.6 Specific Regulatory Requirements

The Environmental Authority (EA) EPML01470513 for the Mining Leases (ML) 70441, 70505 and 70506 was initially granted on 2 February 2016 and further amended in September 2019, July 2020 and most recently April 2022. As stated in the latest EA Permit, Condition E9 requires the numerical groundwater model in the reports titled “Carmichael Coal Mine and Rail Project SEIS: Report for Mine Hydrogeology Report (13 November 2013)” and “Carmichael Coal Mine and Rail Project SEIS: Mine Hydrogeology Report Addendum (24 October 2013)” must be reviewed to incorporate groundwater monitoring data and measured mine dewatering volumes from the GMMP in conditions E4 and E5.

The model review must provide a revised numerical groundwater model which is based on a transient calibration and includes additional model layers for aquifers below the D seam of the Colinlea Sandstone, and in accordance with the GMMP. Condition E9 states that the revised model must include the following, with the location of the condition met shown in brackets within this report:

- a) a review of the hydrogeological conceptualisation used in the previous model (Section xx);
- b) an update of the predicted impacts (Section xx);
- c) a revised water balance model (Section xx);
- d) a review of assumptions used in the previous model (Section xx);
- e) predictions of changes in groundwater levels for a range of scenarios (Section xx);
- f) any changes made since the previous model review, including data changes (Section xx);
- g) a justification for the refined model and the outputs of the refined model (Section xx);
- h) an evaluation of the accuracy of the predicted changes in groundwater levels, groundwater flow rates to surface water and recommended actions to improve the accuracy of the model predictions (Section xx); and
- i) an independent peer review and certification that the environmental authority holder has undertaken the review in accordance with all commitments in the GMMP (Appendix x).

In addition to the requirement of meeting Condition E9, a response to past review criticisms has also been undertaken and this is detailed in Section xx.

2 Conceptual hydrogeological model

A review of the existing and updated hydrogeological conceptual model (HCM) has been documented in detail in EMM (2022a). A HCM is a descriptive representation of a specific groundwater system that incorporates knowledge and interpretation of the geological, hydrological, and hydrogeological conditions in the study area. The HCM summarises the hydrogeological understanding of key processes such as recharge and discharge, and the influence of any boundaries or stresses that may have impact on the flow system. The inherently complex groundwater system is simplified in a way that describes the main features and processes controlling groundwater flow.

To provide context for this report, a summary of the HCM is presented in a tabulated format in Table 2.1. The HCM is presented graphically for the pre-mining and during-mining phases in Figure 2.1 and Figure 2.2, respectively. Figure 2.3 and Figure 2.4 show regional interpreted groundwater contours and flow direction for key hydrogeological units, and Figure 2.5 presents an updated conceptualisation related to surface water, groundwater and spring interaction which are discussed in Table 2.1.

Table 2.1 Summary of the conceptual hydrogeological model developed for the CCM

Feature of conceptual model	Summary of key knowledge
Hydrogeological framework	<p>The main stratigraphic units of relevance to the CCM include, from top to bottom:</p> <ul style="list-style-type: none"> • Quaternary alluvium and Tertiary sediments: confined and unconfined aquifers, notably adjacent to the Carmichael River. • Triassic Moolayember Formation: an unconfined aquitard. • Triassic Clematis Sandstone: an aquifer, unconfined in the east and confined in the west. • Triassic Dunda Beds: a confined aquitard. • Triassic Rewan Formation: a confined aquitard. • Permian Bandanna Formation: alternating confined aquifers (interburden and coal seams). • Permian Colinlea Sandstone: alternating confined aquifers (interburden and coal seams). • Early Permian Joe Joe Group: considered the geological basement in this region. <p>In addition, a distinct weathering profile, which crosscuts Permian and Triassic sediments, exists above the “fresh” Triassic sediments. The base of the weathering shows a distinct thickening towards the scarp and is likely to impede vertical recharge from rainfall, where it exists.</p>
Faults and structures	<ul style="list-style-type: none"> • There is an absence of significant regional faults in the area. • There are only four minor faults interpreted within the coal strata, with previous SEIS assessments estimating vertical throws of between 20 m and 40 m. These faults are generally oriented in an east-west direction. • As part of the Rewan Formation Connectivity Research Plan (RFCRP), studies have shown very little evidence of faulting at least in the Rewan Formation and above. Juxtaposition analysis suggest faults would have throws less than 25 m and maybe as small as 10 m. • There are artesian pressures in the Clematis Sandstone, Dunda Beds and upper Rewan Formation up-gradient of Surprise Creek. There may be a flow barrier (weathering or lineament) in that area restricting outflow from the Clematis Sandstone. • A synform had been proposed during the SEIS phase, with a northeast to southwest fold axis that passes broadly through the centre of the site. The synform affects the Betts Creek Beds and Rewan Formation and the fold axis tends to align with a regional potentiometric ‘low’. • Two alternative conceptualisations have been recently proposed by EMM (EMM 2022a) as an alternative to the synform: local faulting or a permeable Joe Joe Group acting as an underdrain. The local fault (or higher permeable zone) is conceptualised to cut across the Bandanna, Colinlea and Joe Joe Group mainly within the lease area.
Regional groundwater flow system	<ul style="list-style-type: none"> • Regionally, there is a general south to north flow system that diverges at a groundwater divide along the intermontane valley of the Great Dividing Range (GDR). • To the east of the GDR, groundwater tends to flow “up-dip” and converges towards the Mining Leases, for formations above the Rewan Formation. Figure 2.3 shows the interpreted regional groundwater contours for the Clematis Sandstone based on recent data obtained from QLD Globe portal. <p>Groundwater beneath the Clematis Sandstone under pre-mining conditions is observed to flow southeast to the north of the Carmichael River and flow northeast to the south of the Carmichael River. Regional interpreted groundwater contours and flow direction within the Permian coal interburden of the deeper Bandanna Formation and Colinlea Sandstone are shown in Figure 2.4.</p>

Table 2.1 Summary of the conceptual hydrogeological model developed for the CCM

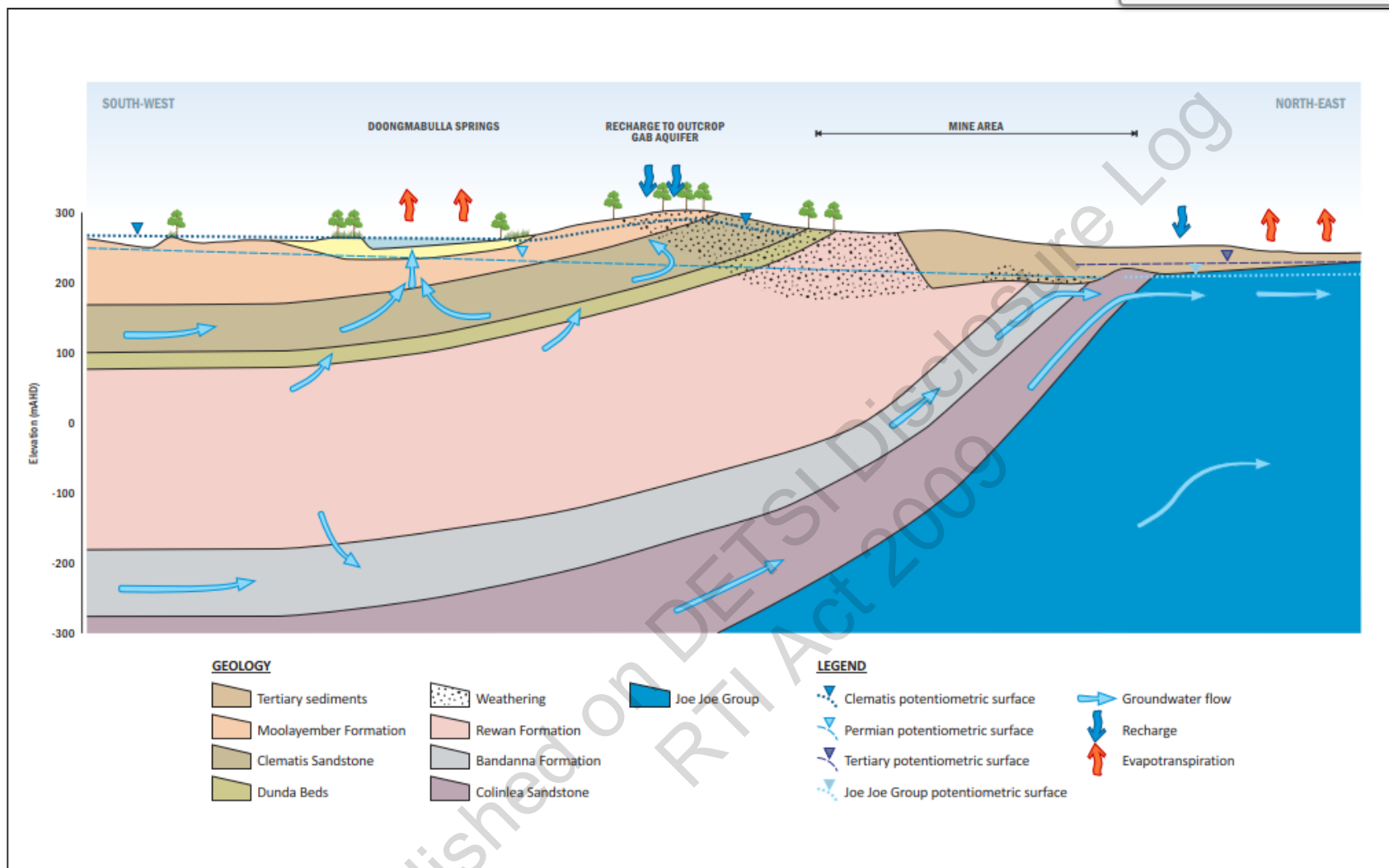
Feature of conceptual model	Summary of key knowledge
Local groundwater flow	<p>Local groundwater flow characteristics differ based on hydrostratigraphic unit (HSU), with the main points summarised as follows:</p> <ul style="list-style-type: none"> • Alluvium: Flow mimics topography and flows west to east along the Carmichael River floodplain. • Tertiary sediments: Flows from south to north. • Clematis Sandstone: Flow converges on the Doongmabulla Springs Complex (DSC), indicating discharge to DSC, baseflow to Carmichael River and evapotranspiration. • Dunda Beds: Flow converges on bore C027P2, near the centre of the mining lease. • Rewan Formation: Flow converges towards bore C008P1, again near the centre of the mining lease. • Bandanna Formation (AB Seam): Groundwater flow converges towards bore C014P2, with flow directions exacerbated by extraction from the mine dewatering bores. • Colinlea Sandstone: Groundwater flow converges towards bore C006P3R and is likely influenced by the local faulting/high permeable zone previously proposed. • Joe Joe Group: Groundwater flow converges on C14003SP and C14004SP and is influenced by the local faulting/highly permeable zone. Flow affected locally by discharge to the Mellaluka Spring Complex (MSC) and pumping from landholder bores.
Recharge and discharge mechanisms	<p>The recharge and discharge mechanisms of each stratigraphic unit can be summarised as follows:</p> <p><u>Recharge</u></p> <ul style="list-style-type: none"> • The alluvium is recharged via surface water infiltration, rainfall infiltration, vertical leakage from underlying units and spring discharge. • Tertiary sediments are recharged via surface water infiltration, rainfall infiltration in outcropping areas and vertical leakage from other units. • The Moolayember Formation and Dunda Beds are recharged via rainfall infiltration into outcropping areas and as well as vertical leakage from other units. • The Clematis Sandstone and Rewan Formation are only recharged through rainfall in outcropping areas. • The Bandanna Formation, Colinlea Sandstone and Joe Joe Group are recharged only through vertical leakage from other units. • Regional groundwater flows towards the local aquifers from the west. <p><u>Discharge</u></p> <ul style="list-style-type: none"> • Alluvium can discharge through baseflow to surface water, post wet season. • All stratigraphic units can discharge via vertical leakage to other units or throughflow. • Alluvium, Tertiary sediments, Moolayember Formation, Clematis Sandstone and Dunda Beds can discharge through evapotranspiration where the depth to water table is shallow. • Spring discharge occurs from the Clematis Sandstone. • Uncontrolled discharge to poorly constructed bores can occur in the Tertiary sediments and Clematis Sandstone. • The Dunda Beds and Clematis Sandstone outcrop along the western boundary of the CCM area. • The Rewan Formation, Bandanna Formation, Colinlea Sandstone and Joe Joe Group subcrop within the CCM area.

Table 2.1 Summary of the conceptual hydrogeological model developed for the CCM

Feature of conceptual model	Summary of key knowledge
Groundwater stresses	<ul style="list-style-type: none"> • Open cut mining will occur, facilitated by perimeter production bores to remove groundwater and allow for dry mining. Drawdown will mainly be associated with targeted Permian coal measures and host materials (Bandanna Formation and Colinlea Sandstone). • Extraction from the Bandanna Formation and Colinlea Sandstone has occurred from August 2019 onwards through dewatering bores. • No dewatering impacts are noted or expected in the alluvium, Tertiary, Clematis Sandstone and Dunda Beds, indicating that the Rewan Formation aquitard is hydraulically isolating the upper units. • Longwall mine panels will develop to the west of the open cut pits, which will target the deeper coal seams. A free draining zone may exist above the longwall panels where groundwater can seep directly from the overlying Rewan Formation. • The mine is likely to reach equilibrium over several decades and perhaps beyond a millennia post-mining, with the system acting as a long-term sink and groundwater flow being directed towards the final voids and underground workings.
Aquifer properties	<p>Prior SEIS modelling and aquifer testing work has determined the following horizontal hydraulic conductivity value ranges for each of the HSUs:</p> <ul style="list-style-type: none"> • Alluvium: 3×10^{-2} – 11 m/d • Tertiary sediments: 2×10^{-4} – 1.7×10^{-1} m/d • Moolayember Formation: 5×10^{-2} m/d • Clematis Sandstone: 1×10^{-2} – 15 m/d • Dunda Beds: 2×10^{-3} – 3 m/d • Rewan Formation: 1×10^{-4} – 0.29 m/d • Bandanna Formation: 1×10^{-4} – 35 m/d • Colinlea Sandstone: 1×10^{-4} – 2×10^{-1} m/d • Joe Joe Group: 2×10^{-4} – 4.1×10^{-1} m/d • As part of the recent RFCRP, the median horizontal hydraulic conductivity of the Rewan Formation was determined to be 2.4×10^{-4} m/d with specific storage values ranging between 3.7×10^{-7} to 6.6×10^{-6}
Groundwater-surface water interactions	<ul style="list-style-type: none"> • Groundwater discharges at the DSC and MSC within the study area. • Springs may supply 15-20% of the water used by floodplain vegetation downstream of the springs. • Rainfall runoff causes ephemeral creeks and rivers to flow periodically, with the greatest flows during the wet season. • Approximately 1% of surface water flows, recharge the alluvial aquifer adjacent to and beneath the waterway, which contributes to sustaining floodplain vegetation through the dry season. • Waterways in the vicinity of the mine are ephemeral and lose water to groundwater, with little to no baseflow occurring. • During the dry season, Dyllingo Creek and Carmichael River rarely flow due to low rainfall, but during the wet season, rainfall can result in streamflow events with water depths of up to 10 m. During these events, water infiltrates through the floodplain and recharges the alluvial aquifer. Figure 2.5 illustrates the conceptual model related to surface water/groundwater/spring interactions west of the CCM.

Table 2.1 Summary of the conceptual hydrogeological model developed for the CCM

Feature of conceptual model	Summary of key knowledge
Groundwater dependent ecosystems	<ul style="list-style-type: none"> The DSC is located approximately 8 km west of the CCM, at the confluence of Bimbah/Cattle Creek, Dyllingo Creek, Carmichael Creek and Carmichael River. The MSC is located to the south of the CCM. Water discharged from the springs typically supports vegetation at the spring location. At some locations, the entire discharge volume is lost to evapotranspiration, while at other locations, wetlands are formed due to larger discharge volumes. Isotope testing strongly suggests that the water from the DSC is more likely to be sourced from groundwater originating in the underlying Triassic Clematis Sandstone rather than from deeper groundwater sources such as the Permian Bandanna Formation, Colinlea Sandstone or the Joe Joe group. The MSC is located at the east of the Colinlea Sandstone subcrop. Springs are formed via local weak points through the Tertiary sediments.
Climate	<ul style="list-style-type: none"> Annual rainfall in the area is approximately 540 mm (BoM Ulcanbah station 036050; 1937-2021). The majority of rainfall occurs from December to March, with January and February being the wettest months. Potential evapotranspiration is approximately 50 mm per month greater than the average rainfall in January to August, and 100 mm per month greater in September to December. Alluvium, Tertiary, Clematis Sandstone and Dunda Beds hydrographs have a strong correlation with climate, suggesting rainfall recharge and creek flow seepage is an important contributor to the dynamics of the groundwater system. A long-term below average rainfall trend occurring from 2013 onwards may have contributed to a decline in groundwater levels over time, prior to mine commencement.



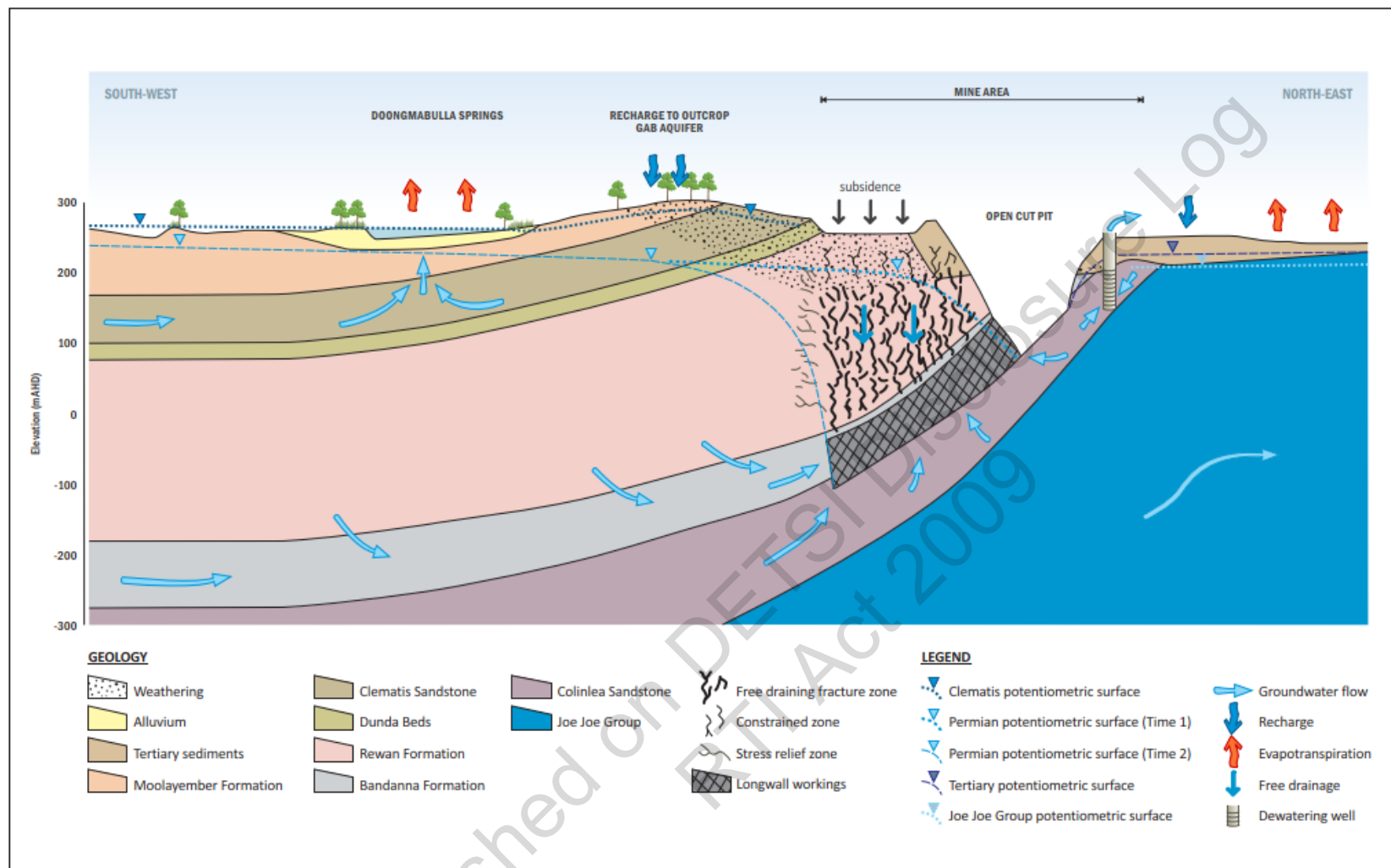
Pre-mining hydrogeological conceptual model

Carmichael Coal Mine: RP1.6 Hydrogeological conceptualisation review and updated groundwater modelling

Bravus Mining & Resources

Figure 12.1

Figure 2.1 Pre-mining hydrogeological conceptual model



Mining hydrogeological conceptual model

Carmichael Coal Mine: RP1.6 Hydrogeological conceptualisation review and updated groundwater modelling

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Figure 12.2

Figure 2.2 Mining hydrogeological conceptual model

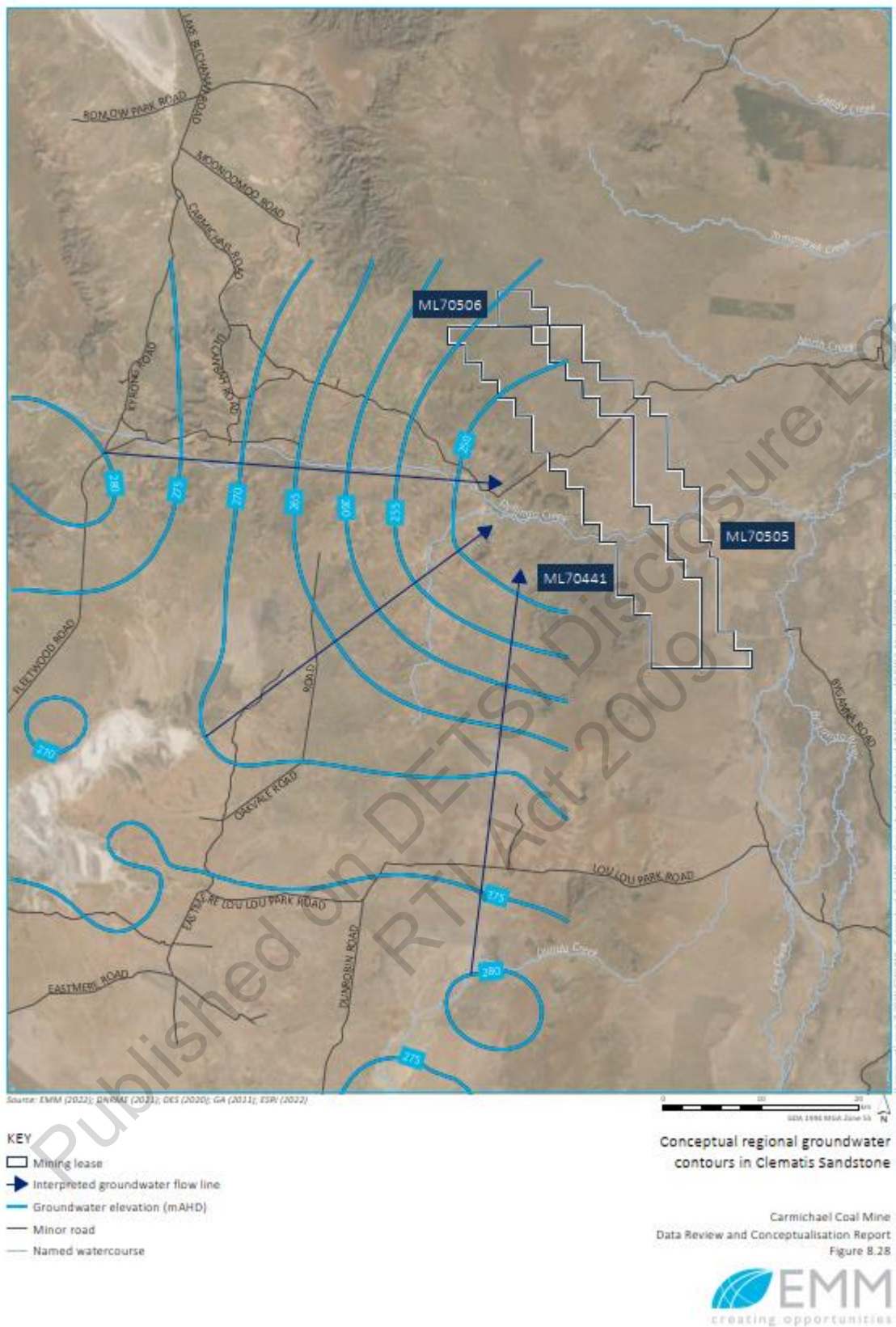


Figure 2.3 Conceptual regional groundwater contours in Clematis Sandstone

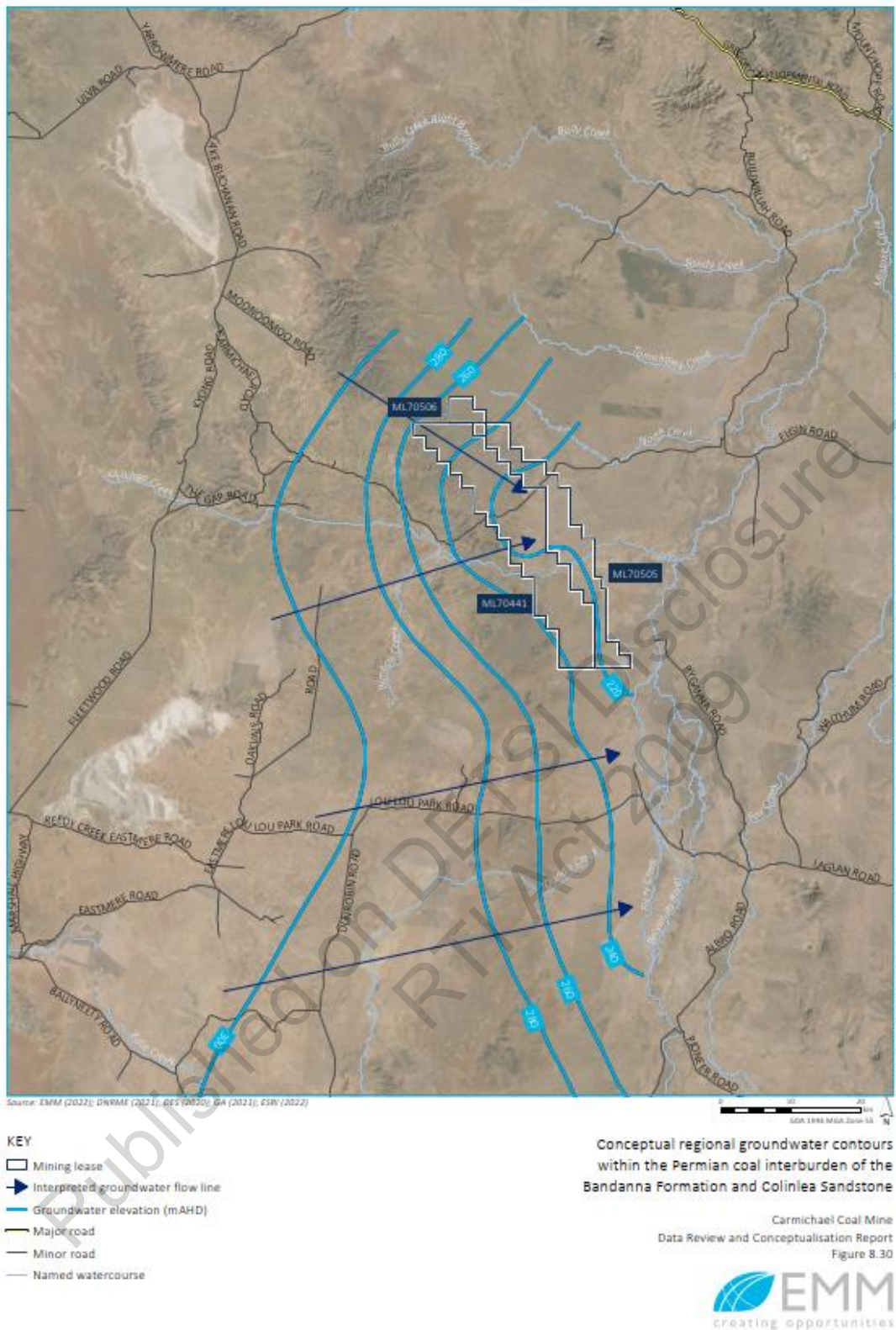
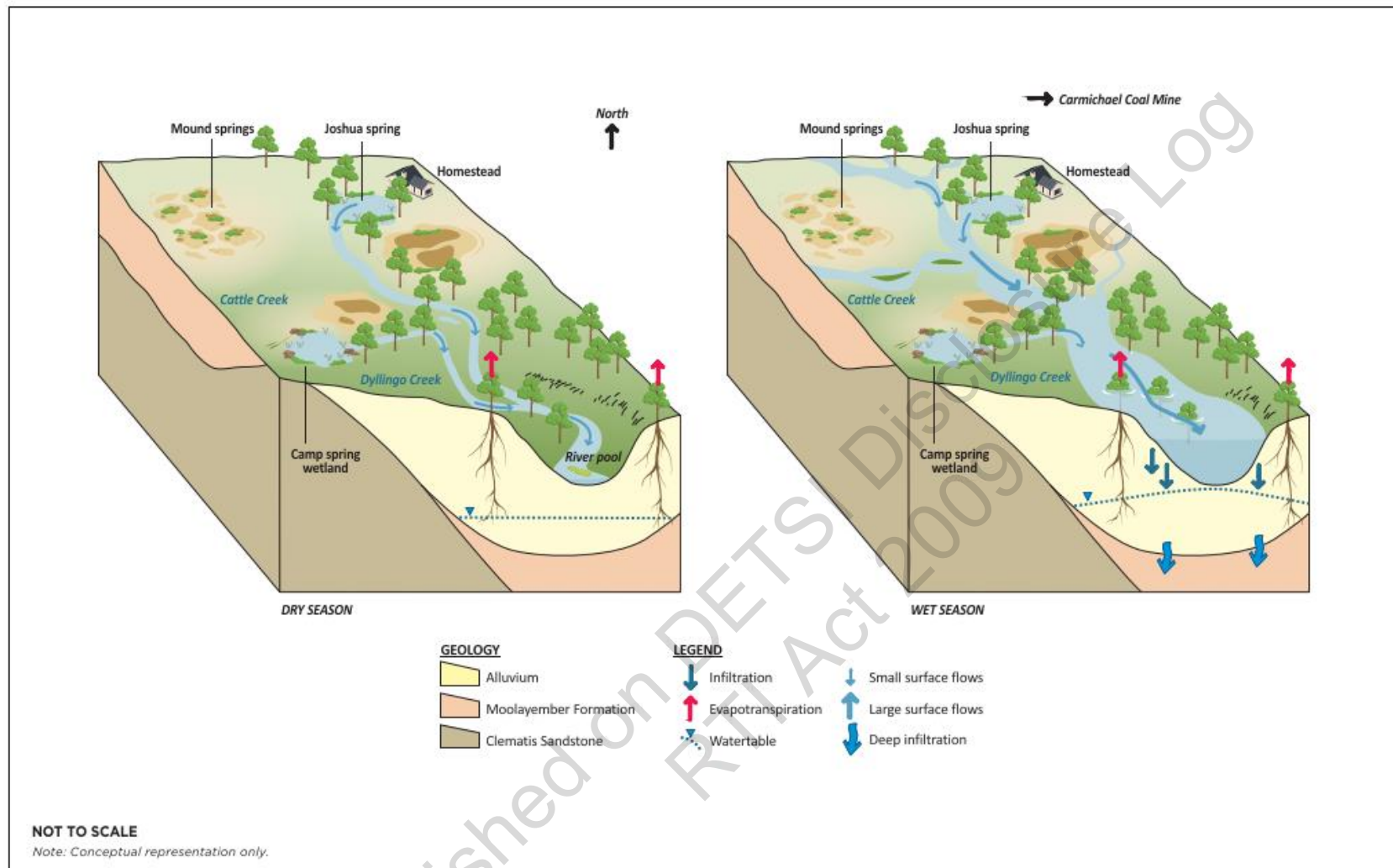


Figure 2.4 Conceptual regional groundwater contours within the Permian coal interburden of the Bandanna Formation and Colinlea Sandstone



Surface water/groundwater interaction conceptual model

Carmichael Coal Mine: RP1.6 Hydrogeological conceptualisation review and updated groundwater modelling

Bravus Mining & Resources

Figure 12.3

Figure 2.5 Surface water/groundwater interaction conceptual model

3 Model design

In response to review comments on the existing numerical groundwater flow model, the updated hydrogeological conceptual model, advances in modelling software, and modern regulatory expectations with regard to predictive uncertainty analysis, a new model has been developed rather than just updating the existing modelling framework.

3.1 Equivalent porous medium

The model was designed using an equivalent porous medium (EPM) approach for each HSU. This approach is commonly used in regional groundwater modelling of fractured rock hydrogeological environments. The EPM method assigns bulk hydraulic properties for rock matrix and associated fracture networks as if they were a single porosity medium such as a granular aquifer (Anderson and Woessner 1991). This approach was adopted for the following reasons:

- in order to simulate regional-scale groundwater impacts a simplified modelling approach was needed; and
- dual porosity and discrete fracture network models require significant detail on fracture/joint orientations, spacings and apertures, which were not available for the geology in the model domain.

It is noted that the EPM approach is appropriate for a regional groundwater model, though potentially at the expense of small-scale prediction accuracy by not capturing the detail of local fracture network properties.

3.2 Software

The numerical groundwater flow model was developed using MODFLOW-USG version 1.10 (Panday et al 2013, Panday 2022). This modelling code contains additional capabilities over previous releases of MODFLOW, utilising a control volume finite difference formulation in which a model cell can be connected to an arbitrary number of other cells. The formulation allows for the development of an unstructured, highly refined model mesh over areas of interest without influencing the regional mesh refinement. In addition, MODFLOW-USG contains an optional Newton-Raphson formulation which improves model stability for processes involving the drying and rewetting of model cells, and this functionality is used.

The Groundwater Vistas 8 (ESI 2021) graphical user interface (GUI) was used to build and run the model, and to conduct some components of post-processing of simulation results. Python scripts were also used for automation of model data pre- and post-processing.

3.3 Domain and spatial discretisation

GHD (2012) developed the existing numerical model domain as a rotated finite difference grid with active area based on the extent of surface water catchments, measuring approximately 93 km east-west by 108 km north-south (along the axes rotated with the grid). To aid comparison of predictions from previous evolutions of modelling of the CCM with those from the new CCM2.0 model, the domain of the existing regional numerical model was adopted, with some modifications. The domain is presented in Figure 3.1, and is adequately large enough to:

- encompass all mine-related water-affecting features, including mine excavations and groundwater monitoring locations;
- encompass all identified receptors with potential to be affected by mining activities; and
- include model boundary conditions such that regional flow directions can be simulated.

3.3.1 Mesh

An unstructured Voronoi polygon mesh is employed to discretise the model domain, developed using AlgoMesh version 2 (HydroAlgorithmics 2020) to incorporate spatial detail at relevant features. This meshing method is numerically efficient and can handle complex geometries. A Voronoi polygon cell is based on a triangle-generated mesh where normally six triangular cells can be combined into one Voronoi cell, thus significantly reducing the number of model cell elements, while providing the flexibility to represent the geometry of irregular features in the mesh. The ability to implement spatial refinement at areas of interest only (without refinement propagating across the whole domain as in older versions of MODFLOW) allows simulation of details at mine and receptor scales in a regional scale model while keeping the number of model cells relatively low. The Voronoi mesh was generated using a 'high' quality setting, resulting in 34,624 Voronoi cells per model layer.

The model mesh employs a cell spacing at model edges of 2,000 m and maximum regional cell spacing of approximately 3,500 m, reducing to smaller cells in areas of interest as follows:

- production bores: 20 m;
- open cut mining area: 500 m;
- underground mining area: 500 m;
- buffer zone around underground mining area to account for horizontal stress relief: 200 m;
- major creeks: 150 m;
- Doongmabulla springs: 200 m; and
- other mapped springs: 100 m.

In addition to the above, further refinement was induced between the edge of the open cut mining area and the southern bank of Carmichael River, to ensure spatial separation of boundary condition cells. Monitoring bores were also incorporated in mesh development to ensure that model nodes are placed at the locations of monitoring, though without cell refinement. The model mesh, presented in Figure 3.1 (regional mesh) and Figure 3.2 (local mesh at mine site), contains all pertinent hydrologic and proposed engineered water management features.

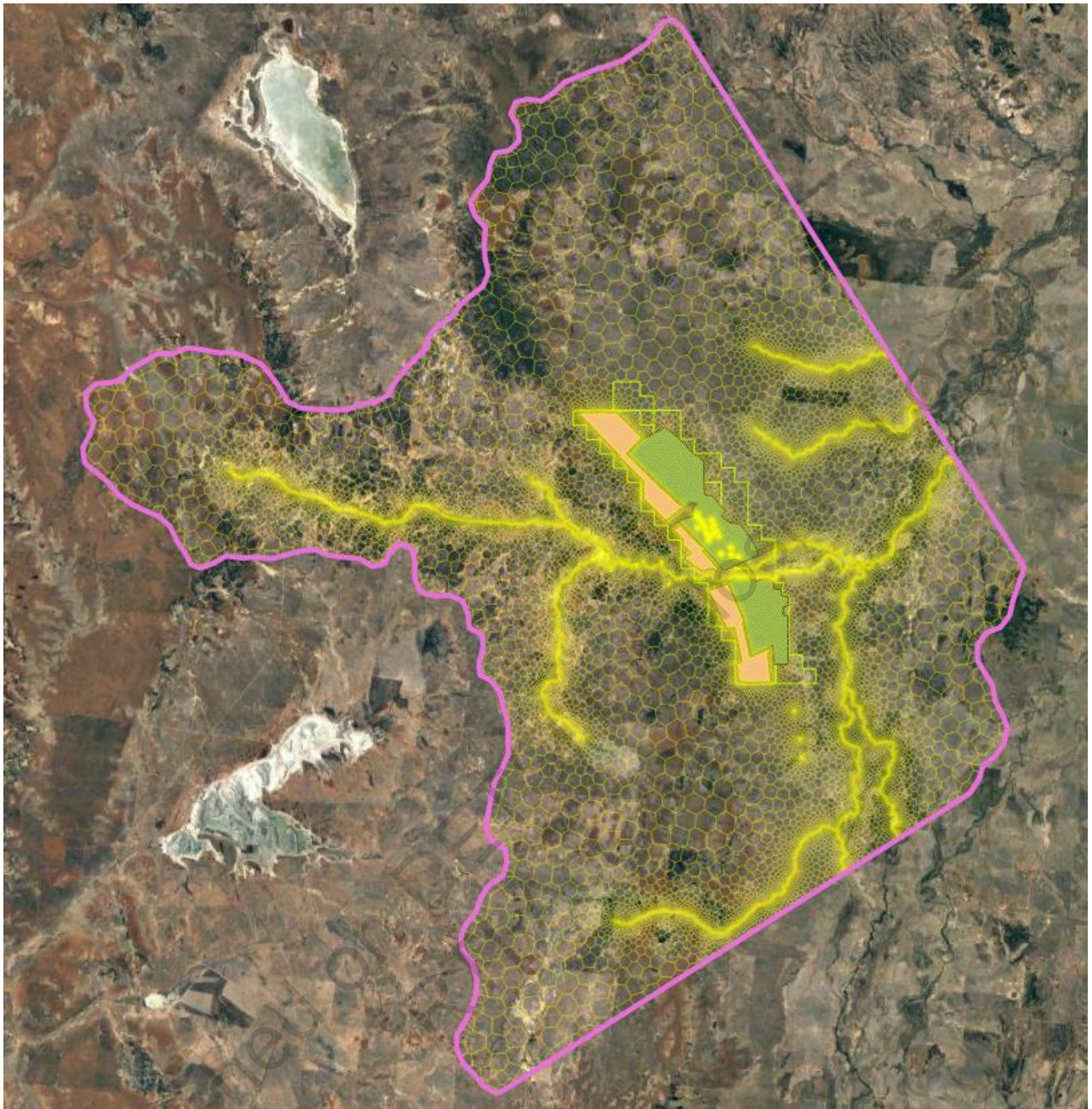


Figure 3.1 Model domain and Voronoi mesh

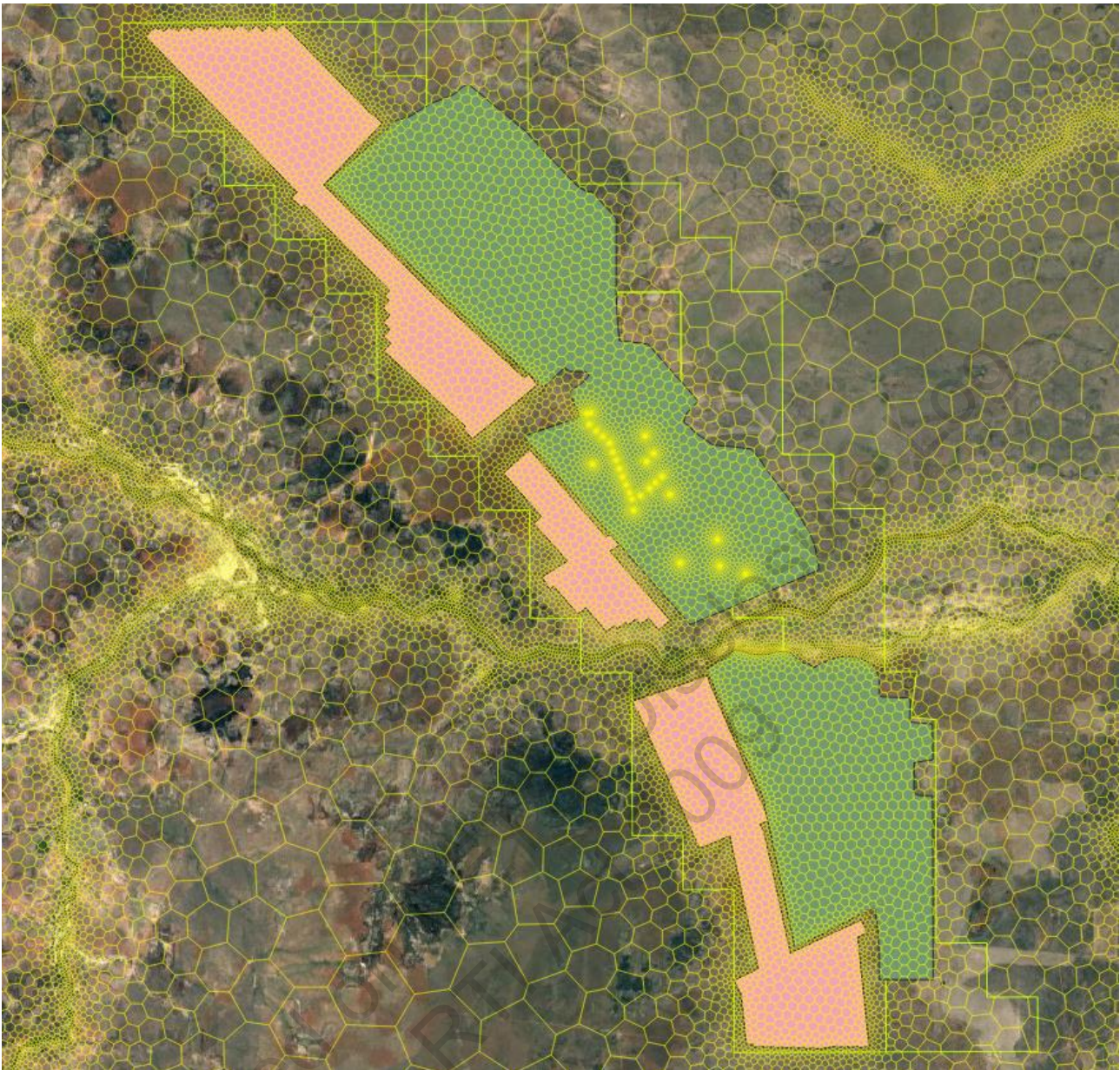


Figure 3.2 Voronoi mesh in mine area

3.3.2 Layers

The HSUs in the study area have been described in EMM (2022a) and summarised in Section 1.6. Based on the objectives listed in Section 1.1 and the conceptual hydrogeological understanding, a minimum of 14 layers were required to represent the key HSUs in the model domain.

Surfaces for the top/bottom of the key regional HSUs were developed using data from multiple sources including:

- coal seam elevation surfaces developed by Bravus;
- geological contact elevation mapping based on borehole data (logs and geophysics) from Bravus;
- updated structural geological layers developed by Titus Murray using specific lithological and structural interpretation software (Murray 2022); and
- bioregional assessment layers (Bioregional Assessment Programme 2014).

The top of the model is set at topography and the base of the model is set 100 m below the top of Joe Joe Group, sufficiently deep below the base of mining to allow for regional groundwater flow below the base of the mine. Model layers are described in Table 3.1.

Table 3.1 **Model layer summary**

HSU name	Groundwater model layer	Mine infrastructure / additional notes
Quaternary alluvium	Layer 1 – aquifer	
Weathering zone	Layer 2 – aquitard	
Tertiary and non-alluvial Quaternary deposits	Layer 3 – aquifer	
Moolayember Formation	Layer 4 – aquitard	Unit not present at mine
Clematis Sandstone / Warang Sandstone	Layer 5 – aquifer	
Dunda Beds	Layer 6 – aquitard	
Rewan Formation	Layer 7-8 – aquitard	Divided vertically into two model layers
Bandanna Formation	Layer 9 – aquifer	
Bandanna Formation (AB Seam coal)	Layer 10 – aquifer	Mined coal seam
Bandanna Formation	Layer 11 – aquifer	
Colinlea Sandstone	Layer 12 – aquifer	
Colinlea Sandstone (D Seam coal)	Layer 13 – aquifer	Mined coal seam
Colinlea Sandstone	Layer 14 – aquifer	
Joe Joe Group	Layer 15 – aquifer	

MODFLOW-USG enables groundwater model layers to pinch out and be deactivated. Layers are pinched out where the unit they represent is conceptualised to be absent. The Rewan Formation has been divided into two layers to allow for discretisation of hydraulic property changes with depth.

The top elevations of each model layer are presented in Figure 3.3 to Figure 3.16. Three-dimensional visualisations of the model layering at cross sections aligned perpendicular to and along the strike of the mine are presented in Figure 3.17. These show the regional HSU elevation trends and sub-cropping observed at the edge of the Galilee Basin.

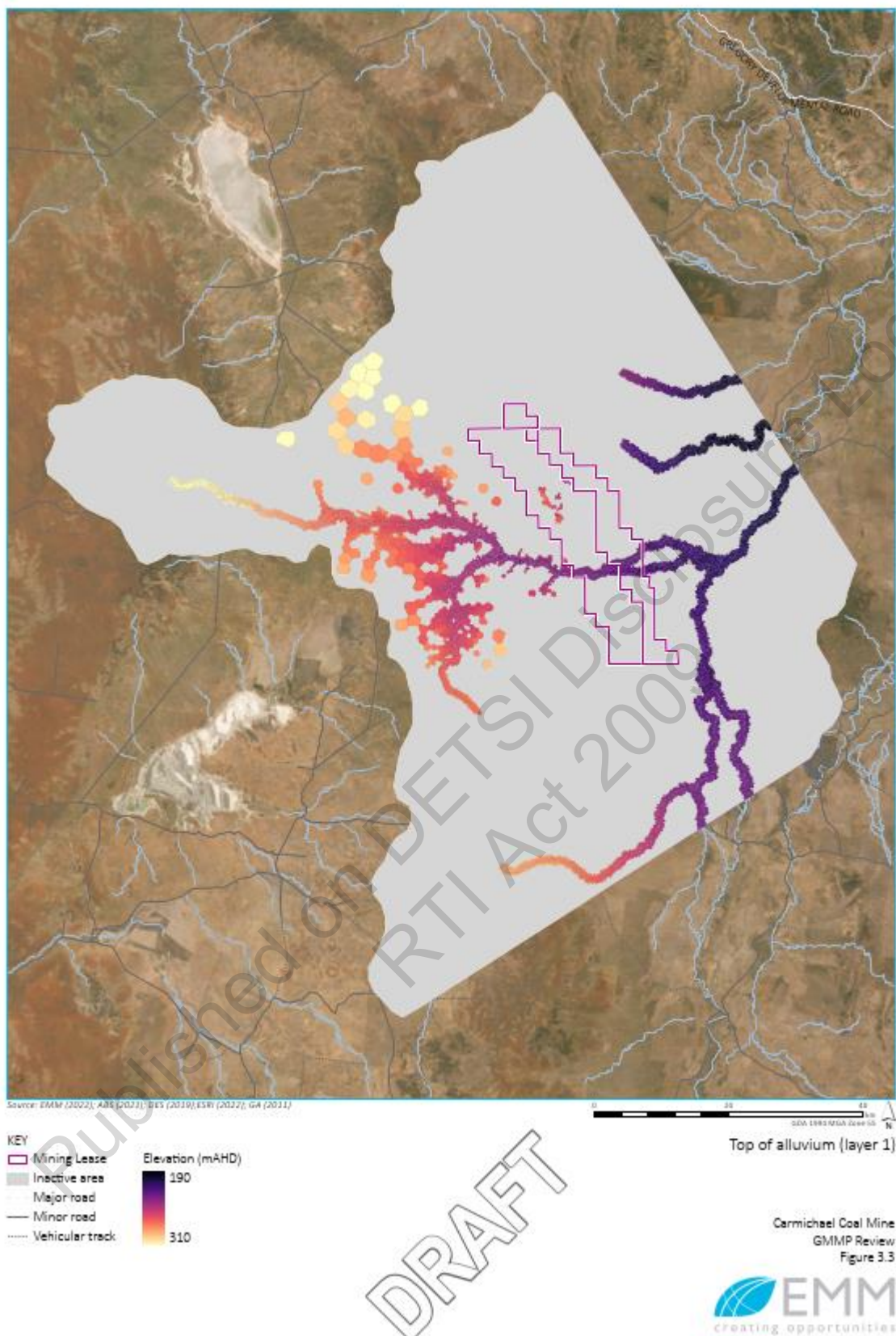


Figure 3.3 Top of alluvium (layer 1)

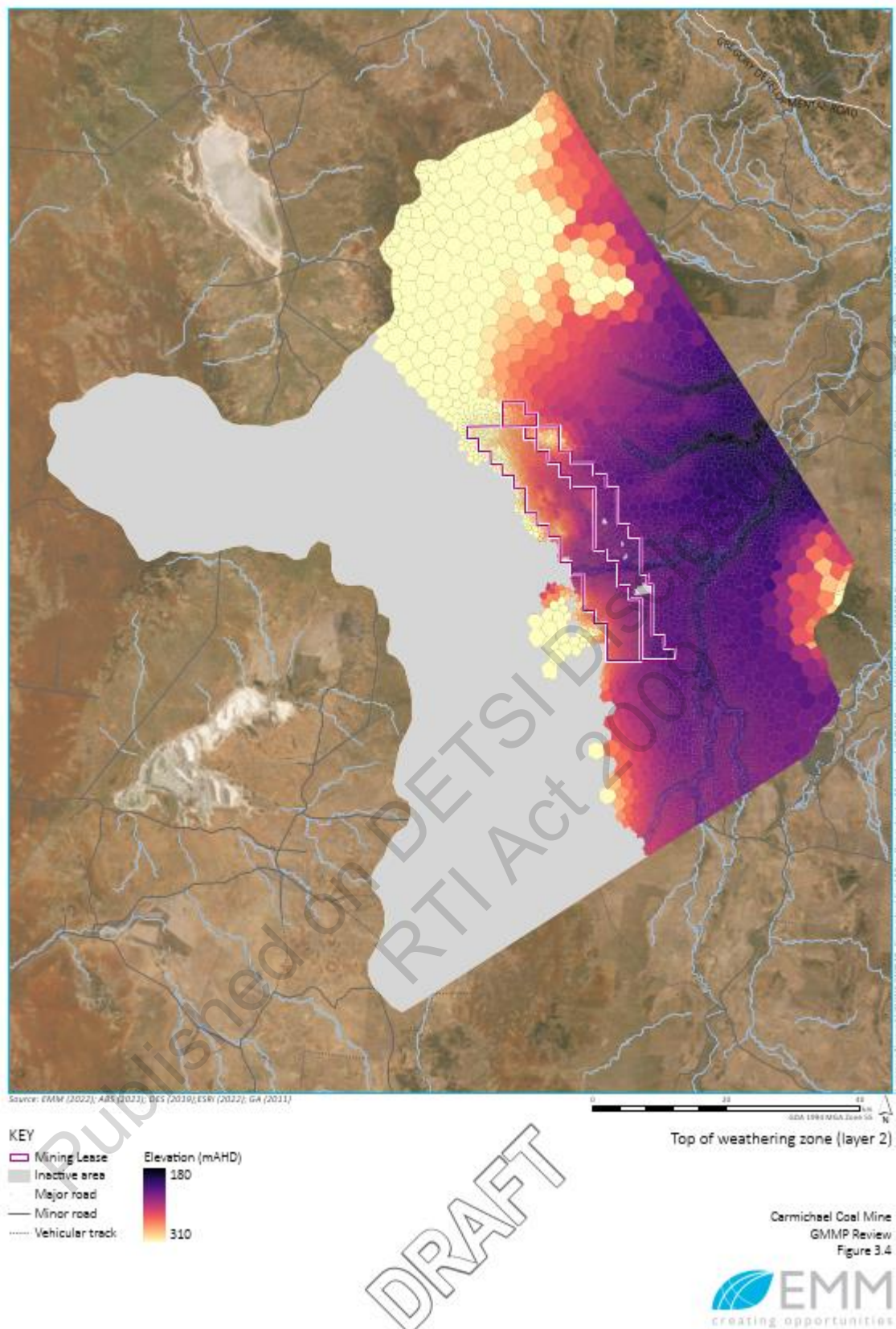


Figure 3.4 Top of weathering zone (layer 2)

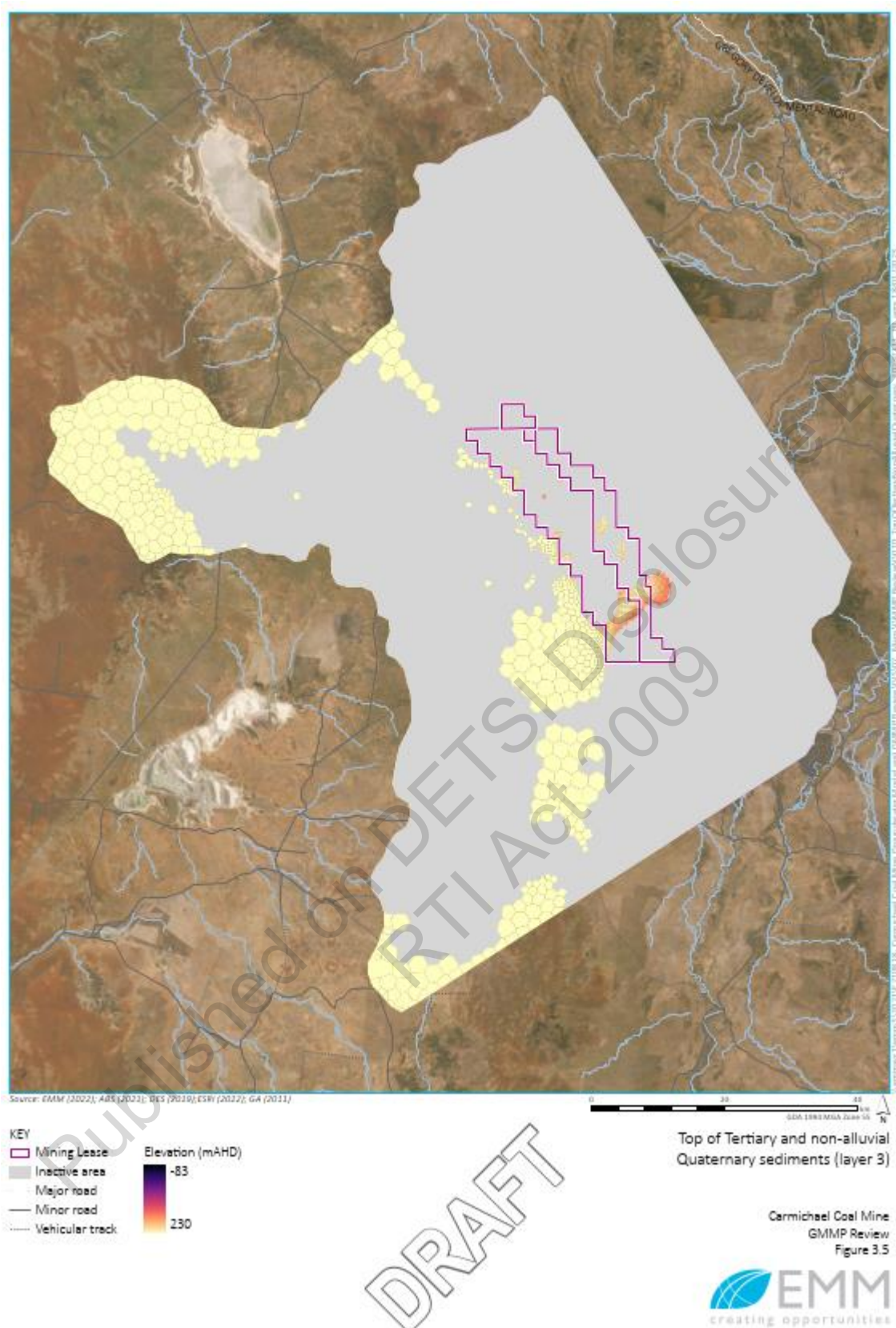


Figure 3.5 Top of Tertiary and non-alluvial Quaternary sediments (layer 3)

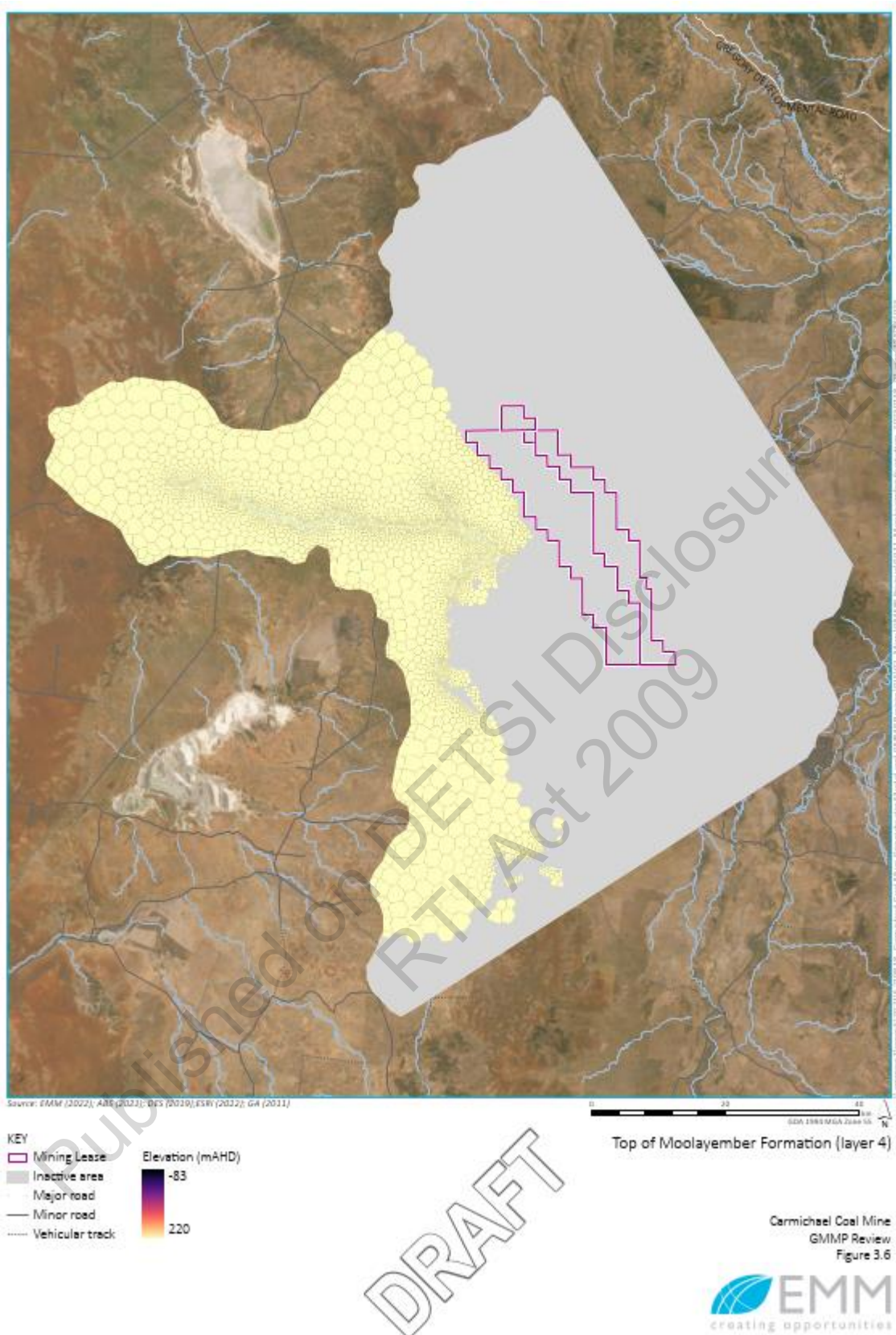


Figure 3.6 Top of Moolayember Formation (layer 4)

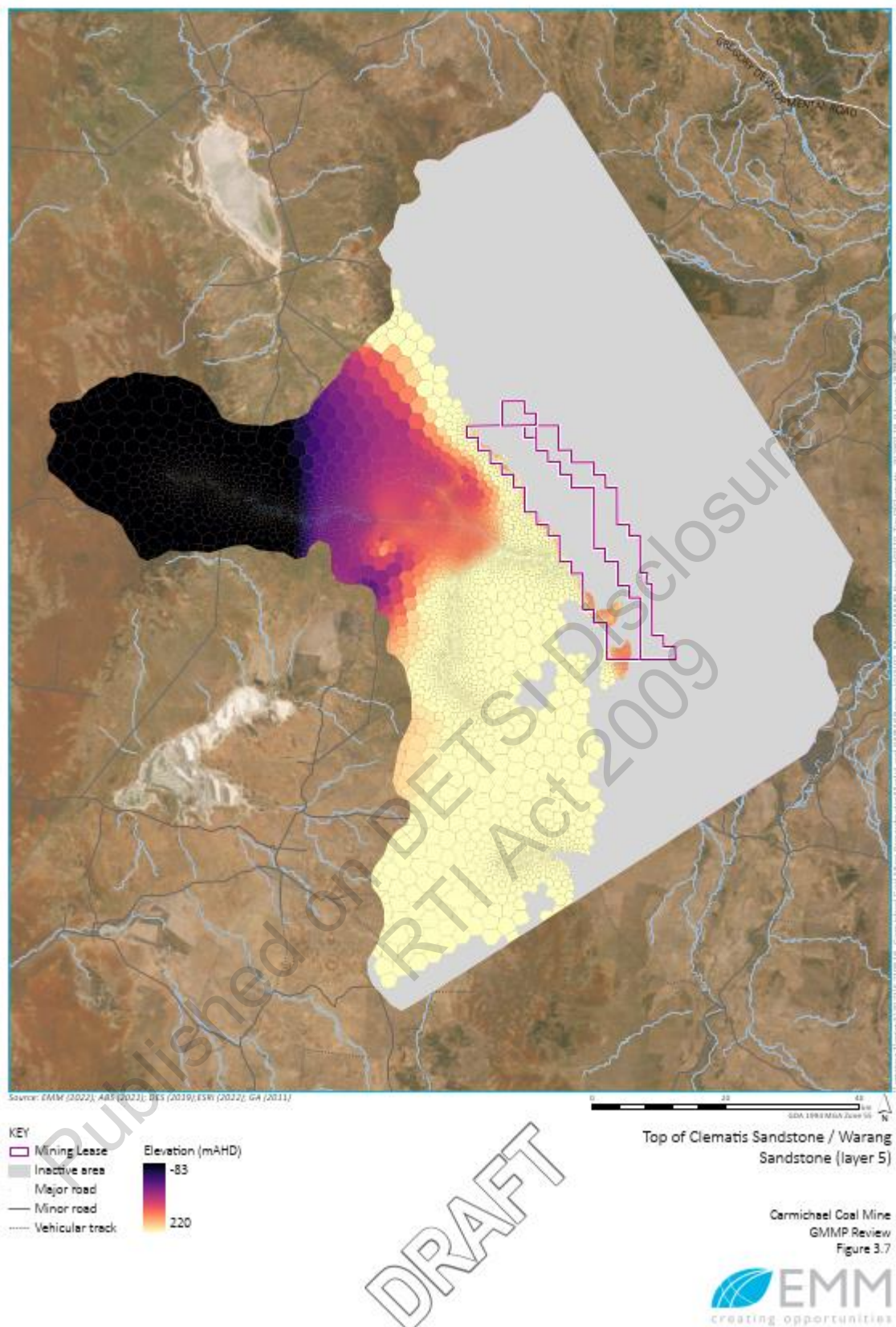


Figure 3.7 Top of Clematis Sandstone / Warang Sandstone (layer 5)

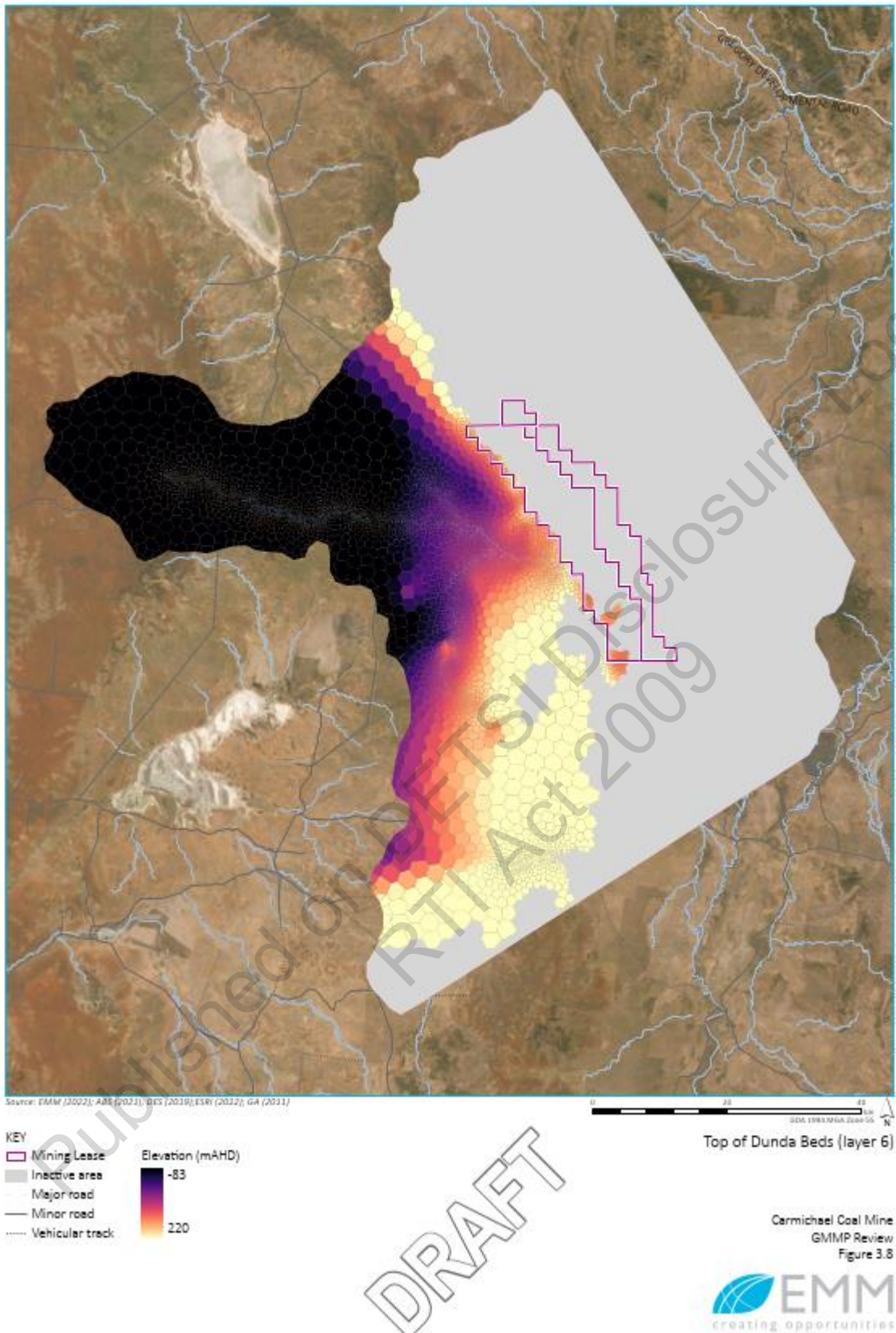


Figure 3.8 **Top of Dunda Beds (layer 6)**

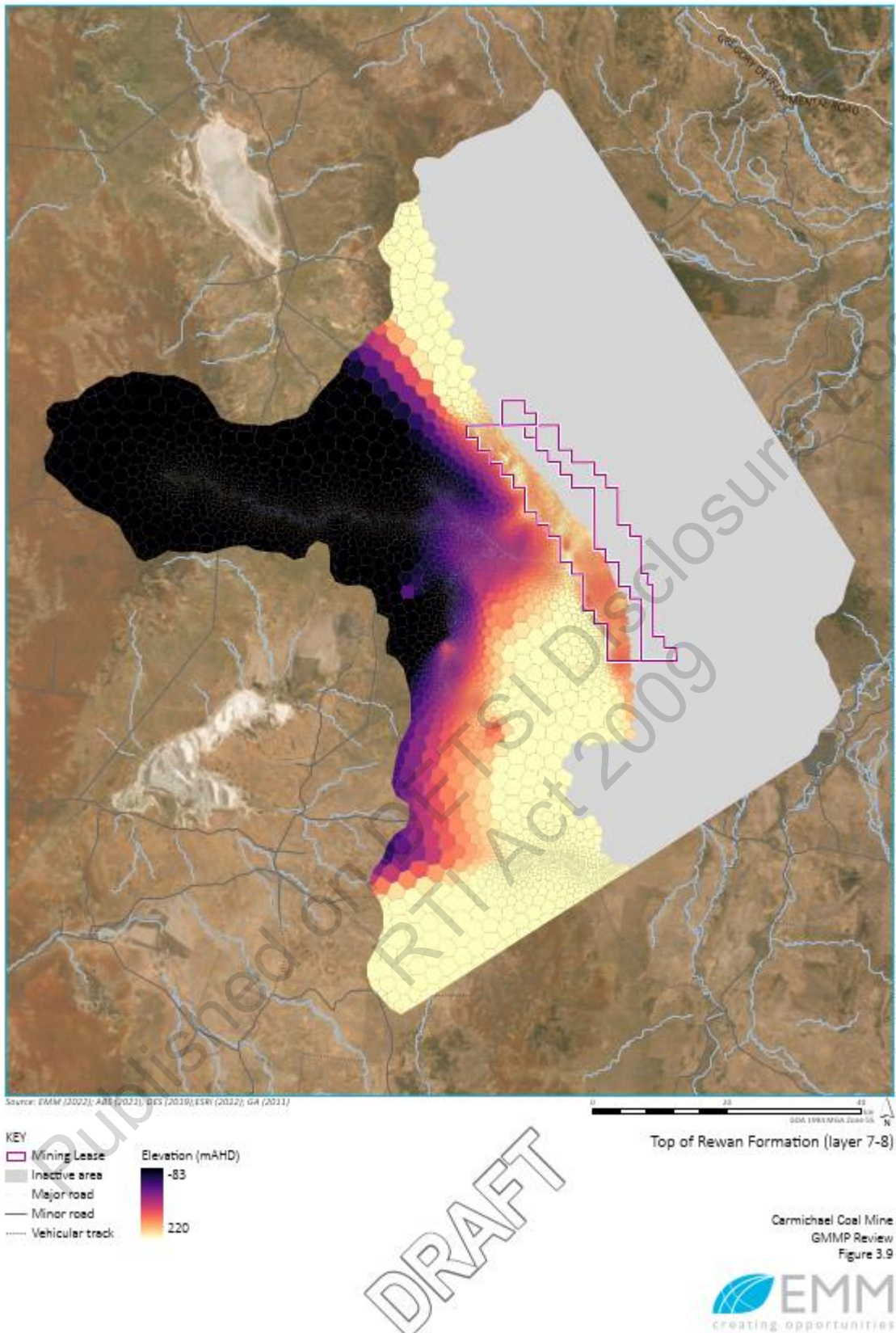


Figure 3.9 Top of Rewan Formation (layer 7-8)

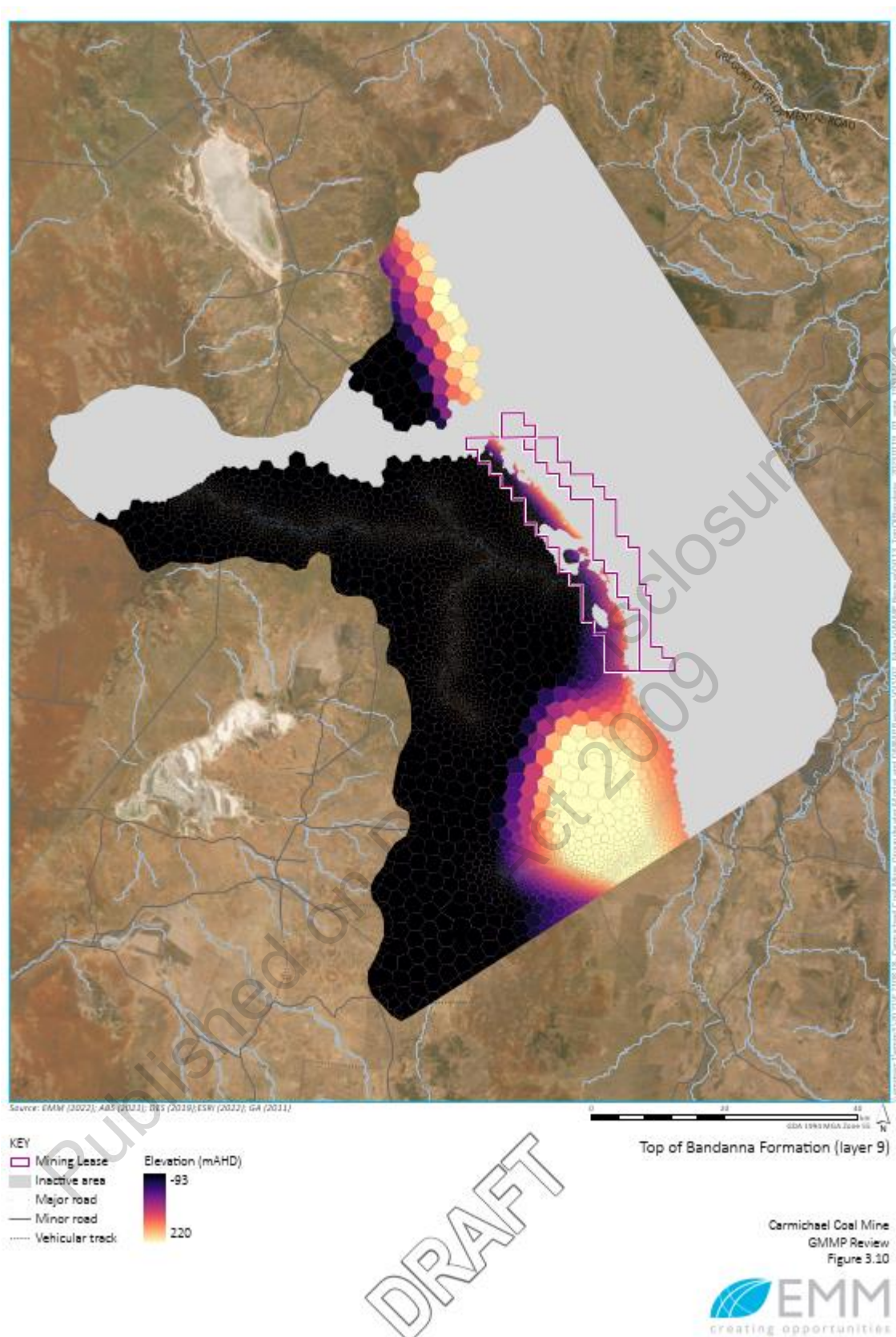


Figure 3.10 Top of Bandanna Formation (layer 9)

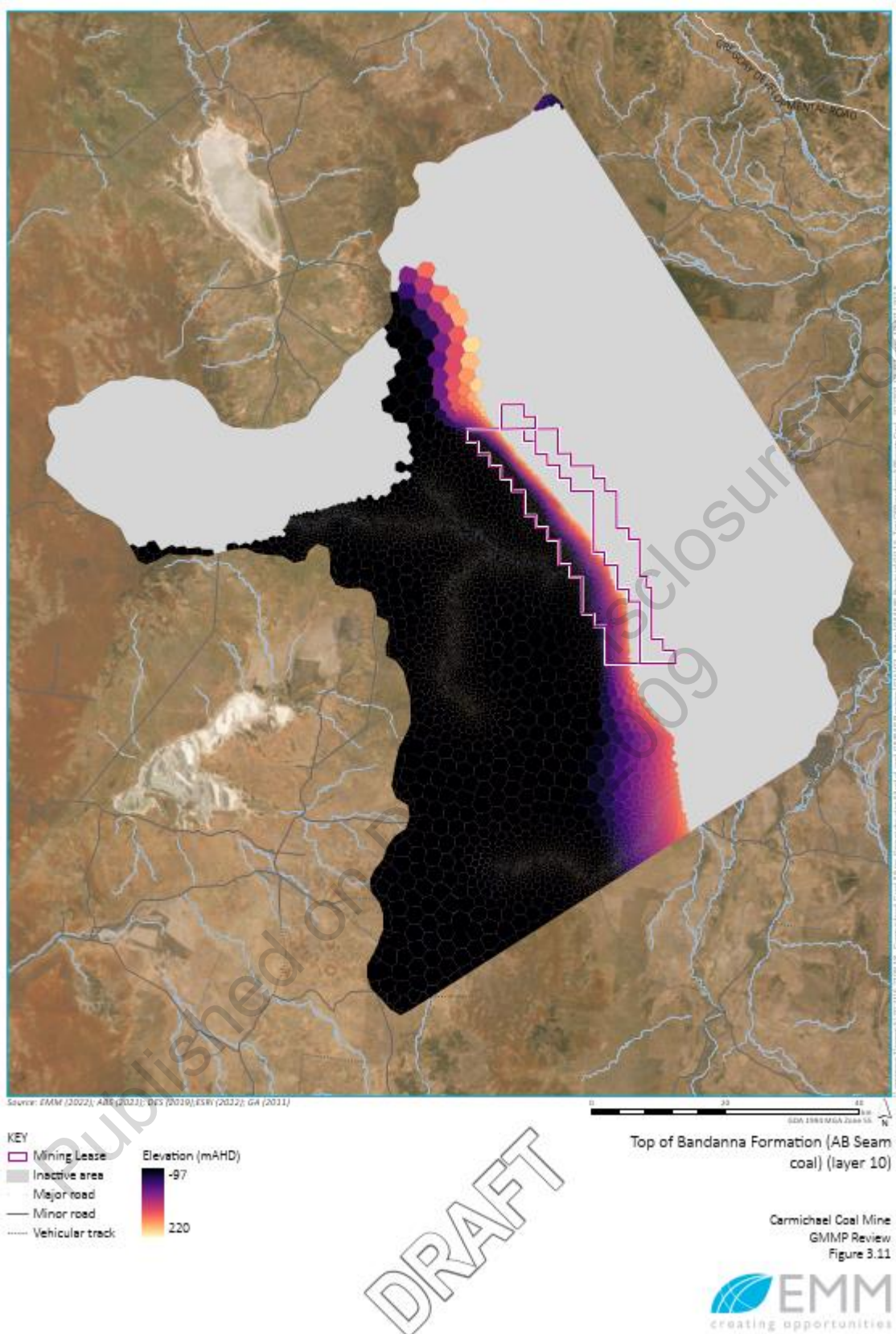


Figure 3.11 Top of Bandanna Formation (AB Seam coal) (layer 10)

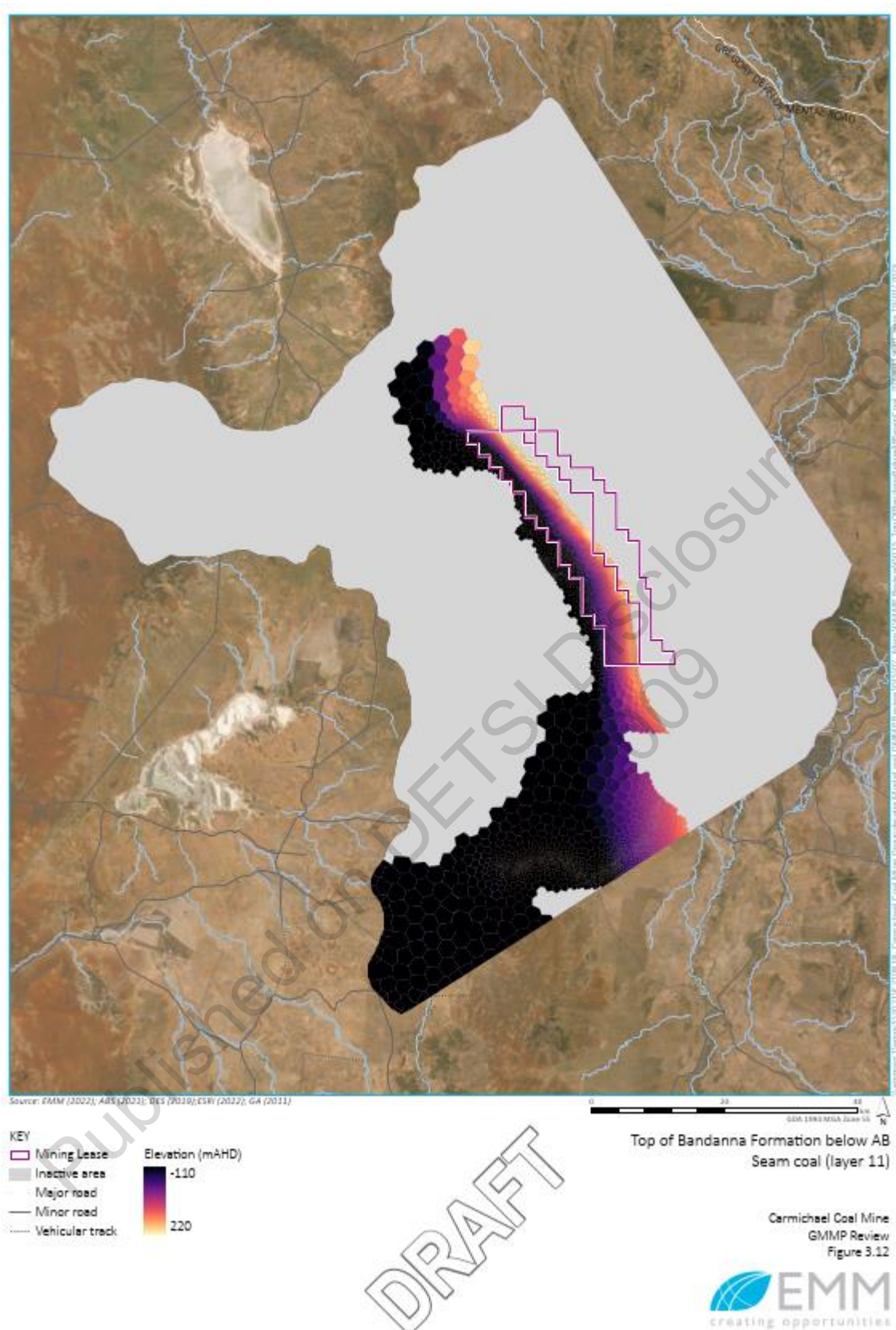


Figure 3.12 Top of Bandanna Formation below AB Seam coal (layer 11)

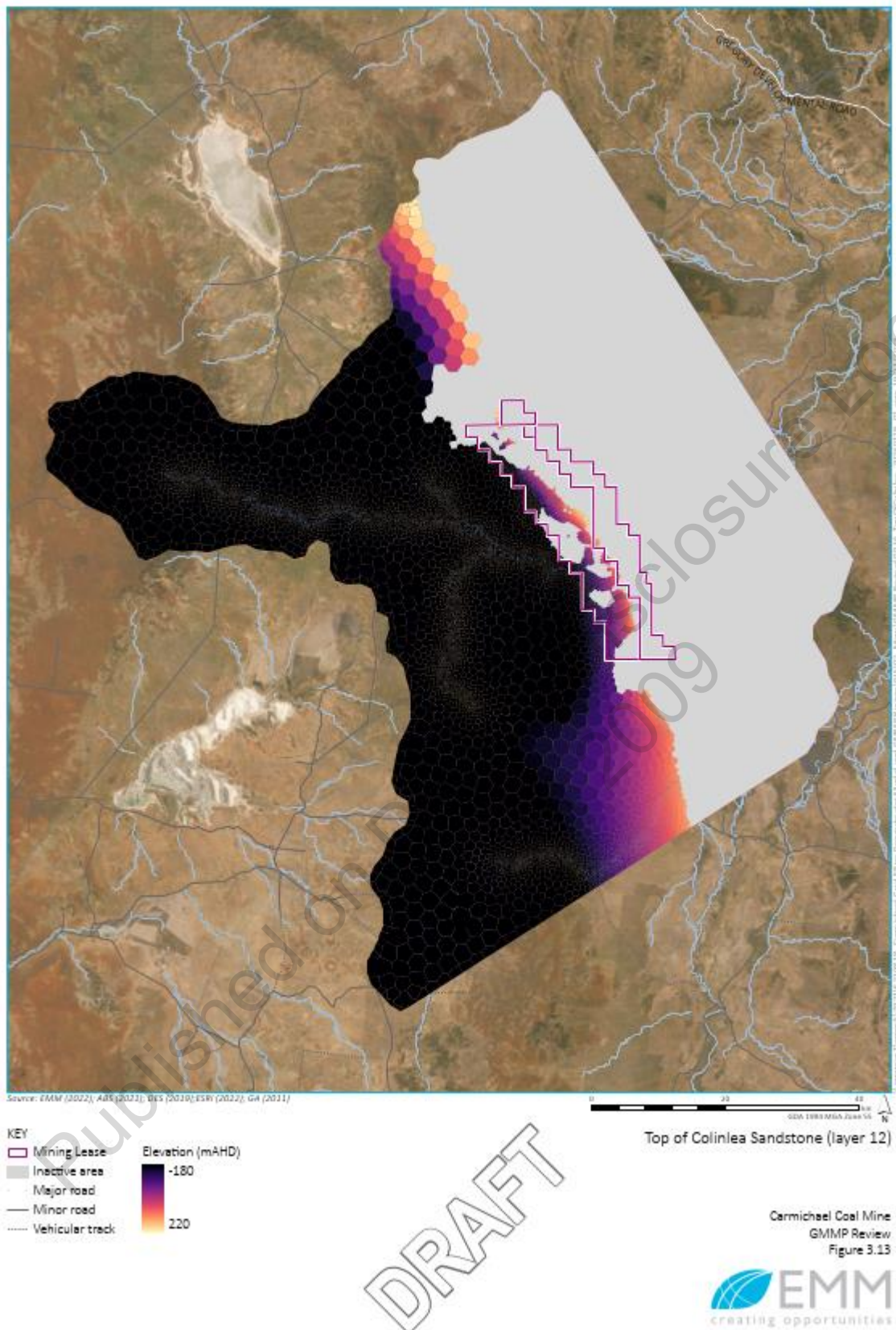


Figure 3.13 Top of Colinlea Sandstone (layer 12)

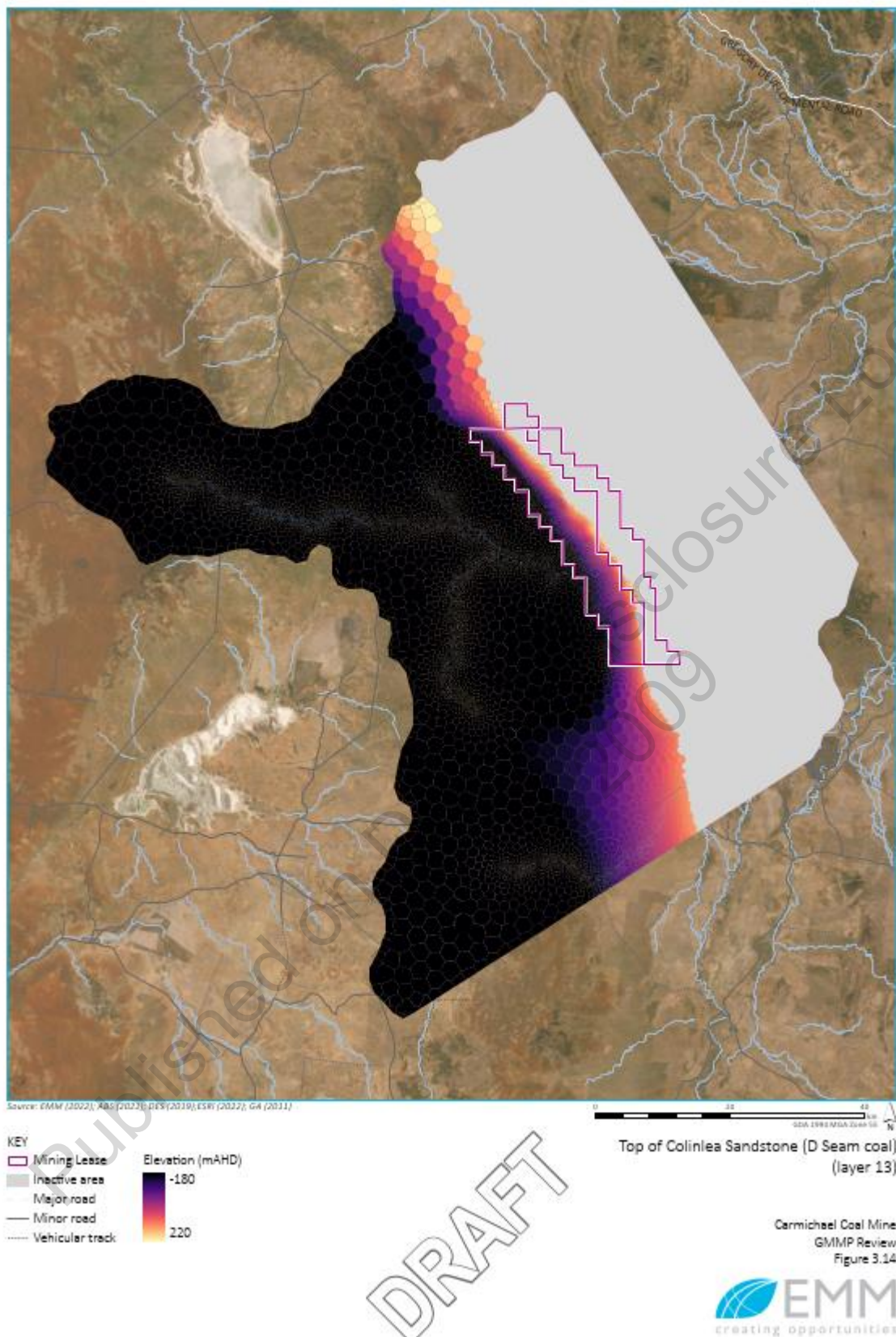


Figure 3.14 Top of Colinlea Sandstone (D Seam coal) (layer 13)

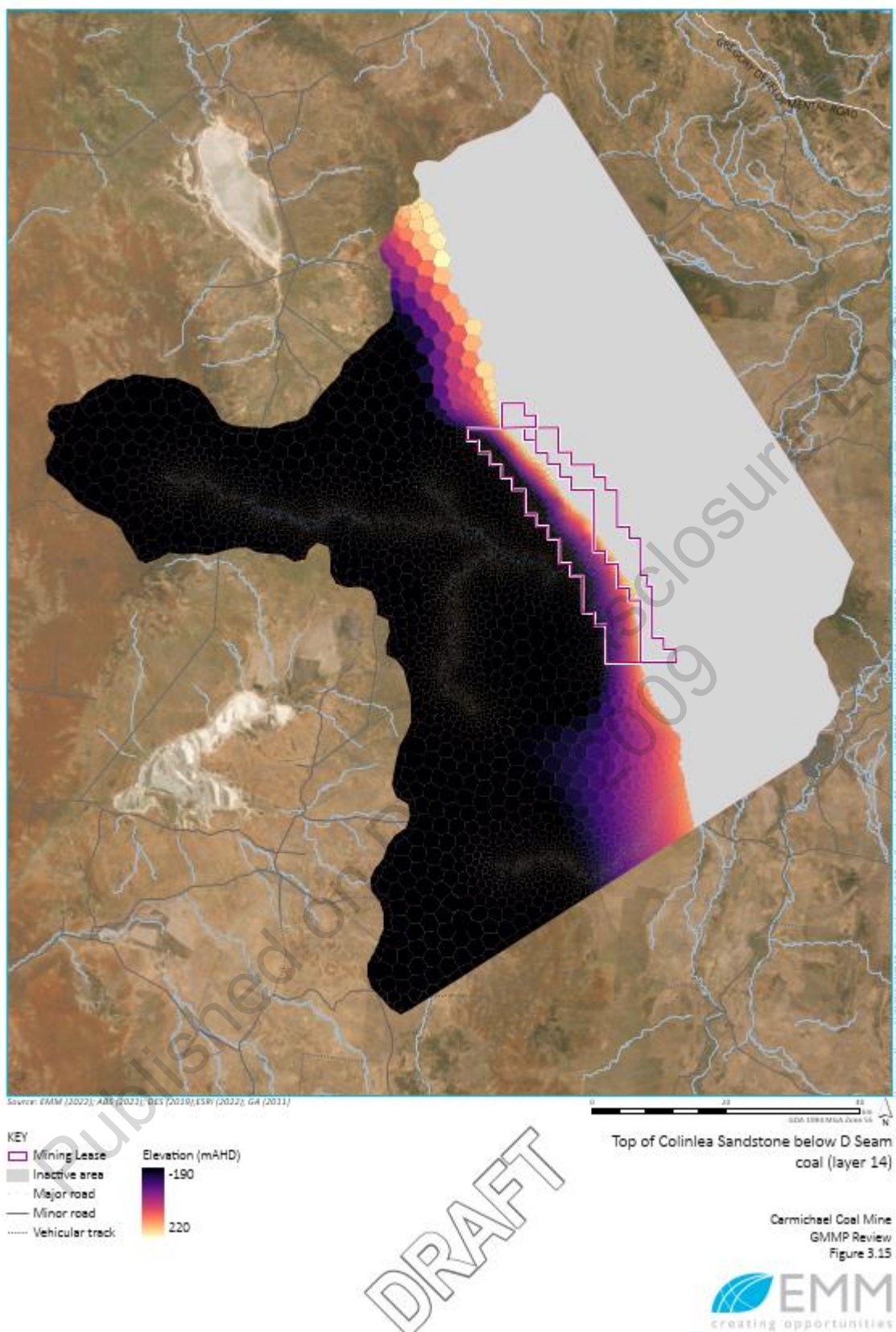


Figure 3.15 Top of Colinlea Sandstone below D Seam coal (layer 14)

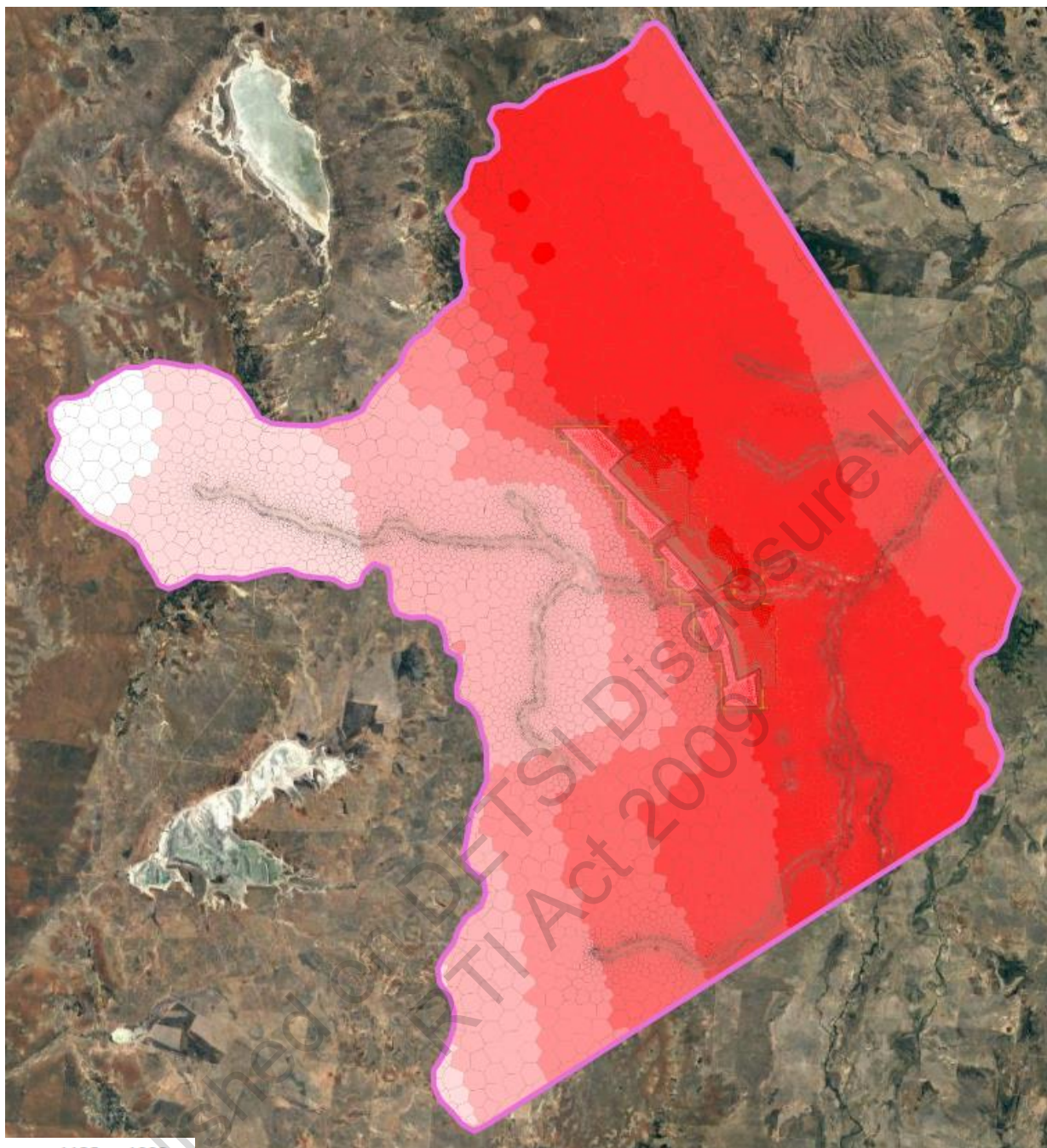
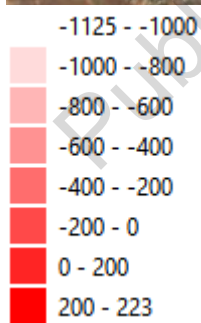


Figure 3.16 Top of Joe Joe Group (layer 15)

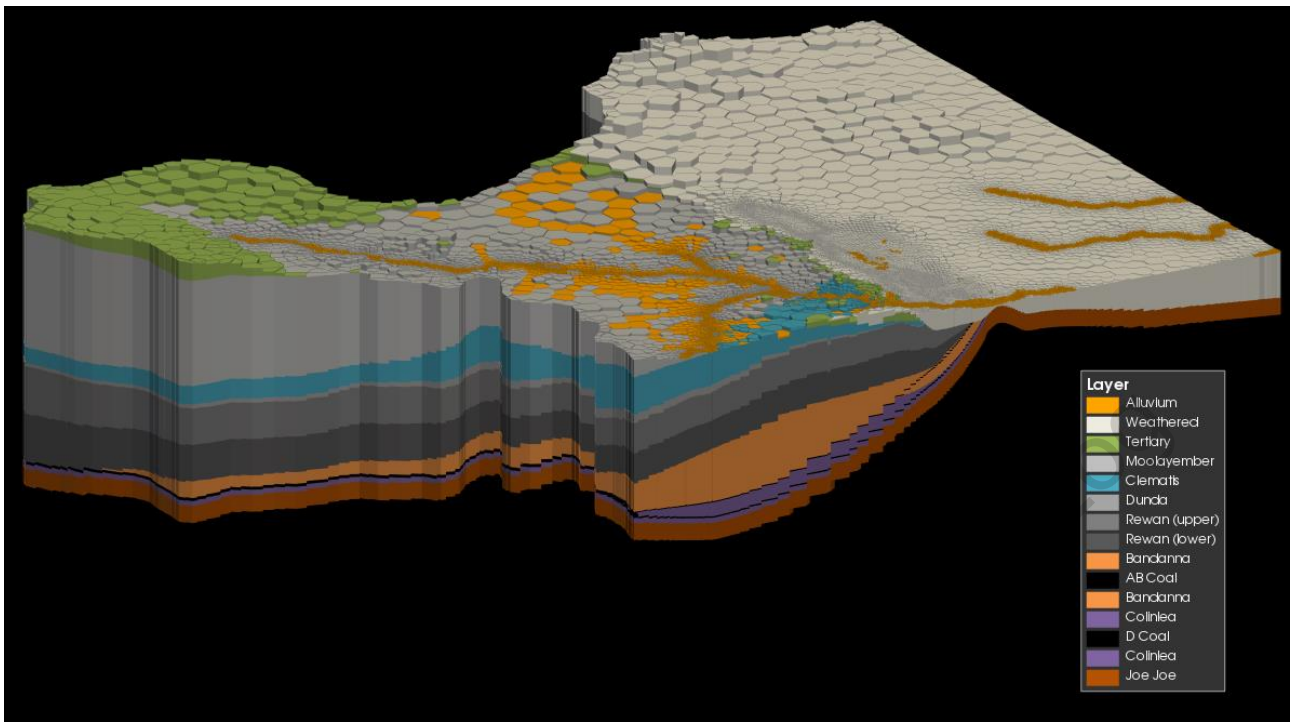


Figure 3.17 3-D visualisation of modelled HSUs

3.4 Temporal discretisation and numerical solution

The history-matching period employs two initial stress periods; one transient stress period run to pseudo-steady state for numerical stability, and one true steady state stress period to establish stable pre-mining groundwater conditions. Following the steady state stress period, 34 quarterly stress periods are employed over the history-matching period from April 2011 to August 2019, followed by 32 monthly stress periods from the commencement of mine dewatering. Starting from April 2022, the predictive mine plan is simulated with 109 part-year stress periods (8 months and 4 months respectively), representing dry and wet seasons. A subsequent final stress period simulates 2,000 years of post-mining recovery. A summary of the model stress periods is provided in Table 3.2.

The adaptive time stepping feature of MODFLOW-USG is employed to efficiently discretise stress periods into time steps such that a numerically stable solution is obtained. The SMS solver is employed to solve the differential equations with a head closure criterion (HCLOSE) of 1×10^{-2} m, using the χ MD linear method and Delta-Bar-Delta/Newton Raphson nonlinear method.

Table 3.2 Model stress periods

Stress period	Stress period duration	Description
1	100 years	Pseudo-steady state stress period run in transient mode to provide numerical stability for the following true steady state stress period
2	Steady state	Develops initial pre-mining conditions in response to modelled hydraulic parameters and boundary conditions
3 to 36	Quarterly	History-matching period, from April 2011 to August 2019 (climate stresses only)
37 to 68	Monthly	History-matching period including mine dewatering, from August 2019 to April 2022
69 to 177	Part-yearly	Predictive period simulating mining activities from April 2022 to December 2076
178	2,000 years	Predictive period simulating 1,000 years of post-mine recovery

3.5 Boundary conditions

3.5.1 Regional groundwater flow

As discussed in Section 1.6, groundwater generally flows across the model domain from the south-west towards the north-east. Constant head boundary conditions (CHD package) are applied at the model boundaries in primary aquifers (alluvium and surficial sediments, Clematis Sandstone, and deeper Permian strata) to simulate lateral groundwater flow to and from the broader groundwater system. Conceptual hydraulic head contours were taken from the Bioregional Assessment Programme (2015) for the Bandanna Formation, and Colinlea Sandstone. Groundwater contours were developed for the Clematis Sandstone in consultation with DES and using data available from QLDGlobe. Data for the shallow sediments and Joe Joe Group were sourced from Turvey et al. (2015), with representative measured steady state groundwater heads used to infer regional contours.

The modelled constant head boundaries are shown in Figure 3.18 to Figure 3.22. The hydraulic heads assigned to the constant head boundary conditions are set to the inferred elevation of the potentiometric surfaces, ranging from 190 mAHD in the eastern area of the model domain to 290 mAHD in the western and south-western corners. By assigning constant head boundary conditions around the model edge, not only at inferred locations of inflow or outflow prior to mining, the model is able to simulate changes to flows across the model boundary that may arise due to simulated mining activities, regardless of whether those locations are conceptualised as being inflow or outflow areas prior to mining. Boundary cells are inactive at locations where an HSU is pinched out; this

includes the eastern portion of the model domain for subcropping units (Clematis Sandstone, Bandanna Formation, and Colinlea Sandstone).

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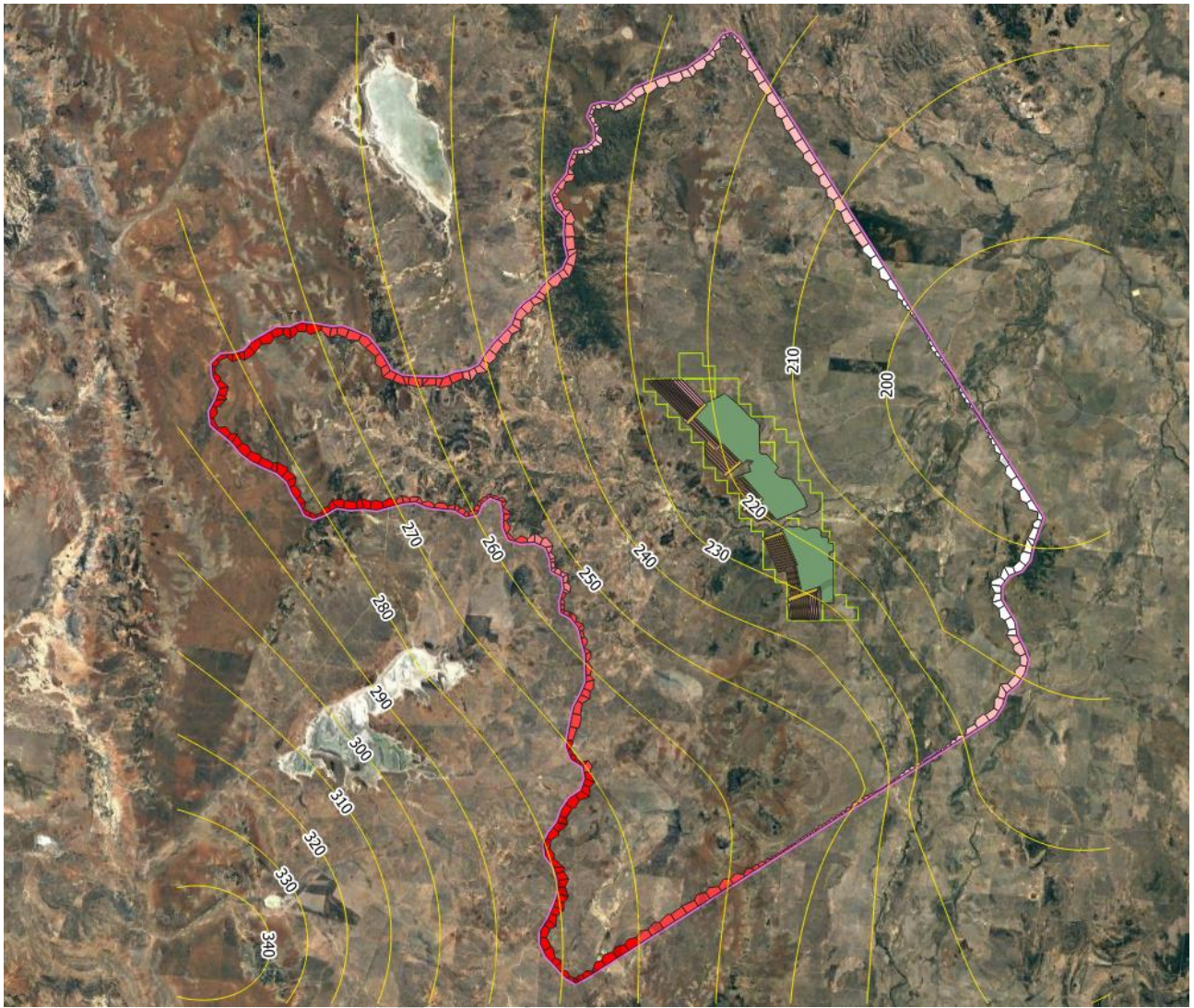


Figure 3.18 **Modelled regional boundary conditions in surficial layers**

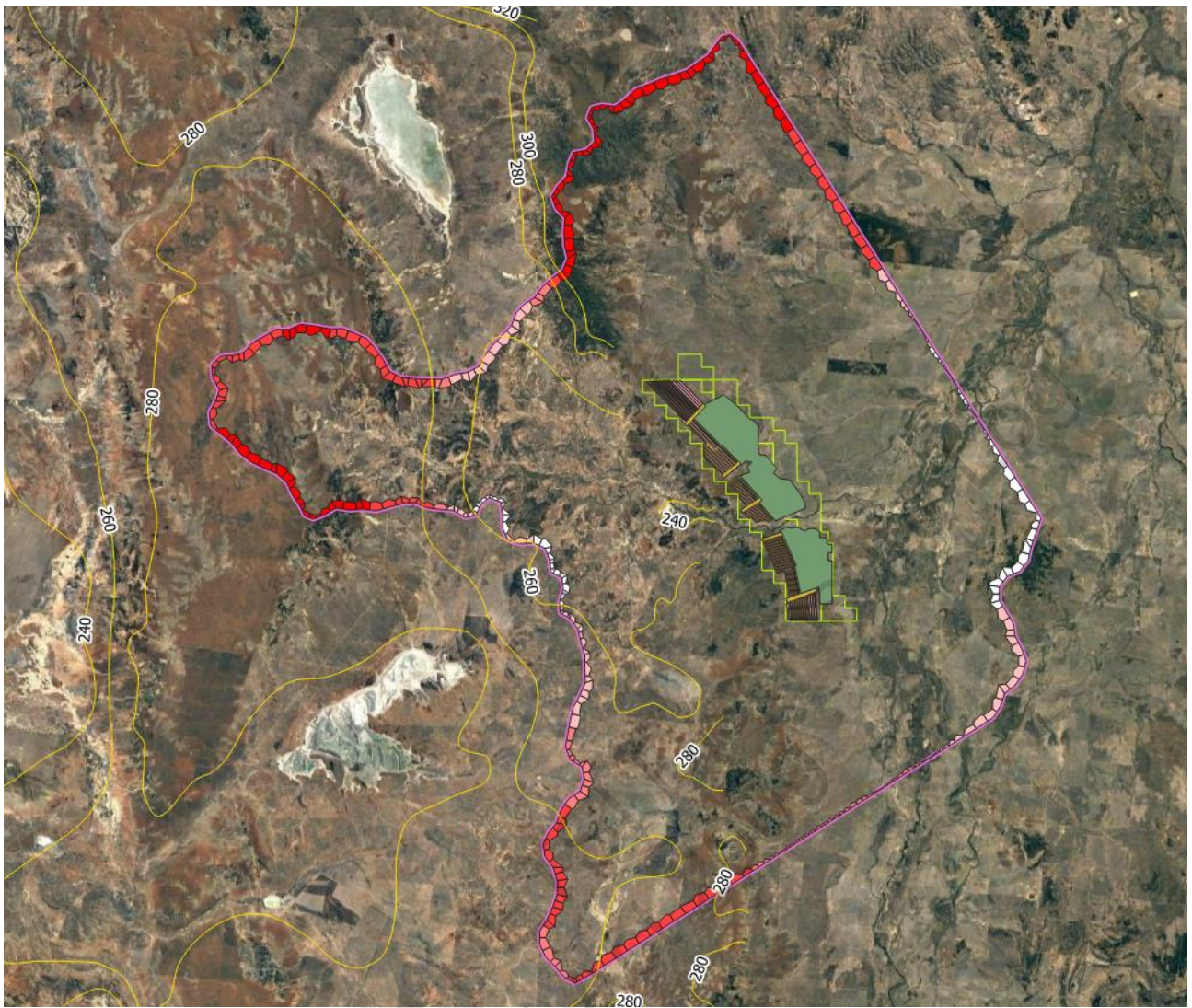


Figure 3.19 **Modelled regional boundary conditions in Clematis Sandstone**

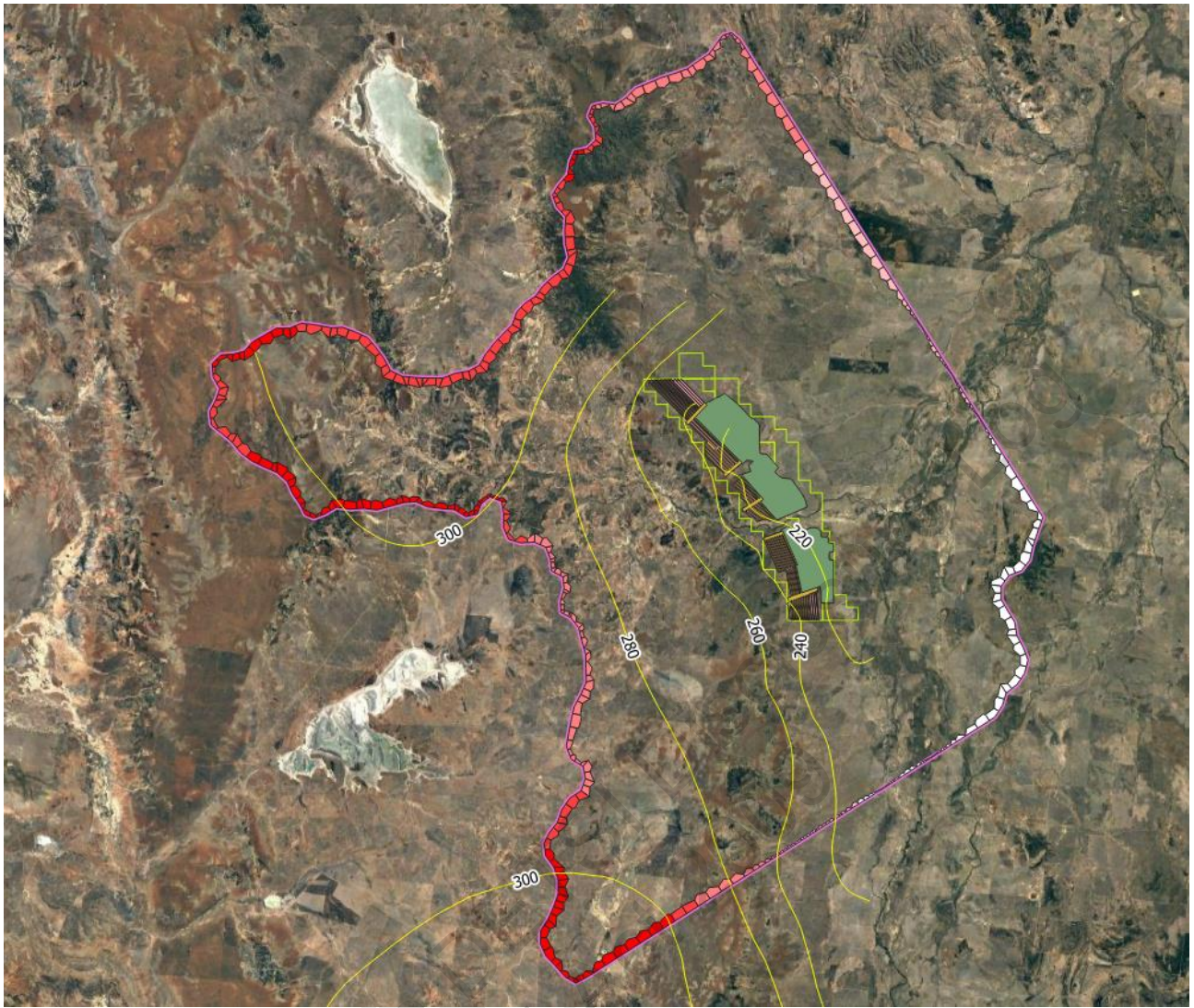


Figure 3.20 Modelled regional boundary conditions in Bandanna Formation (coal seam overburden) and AB Coal

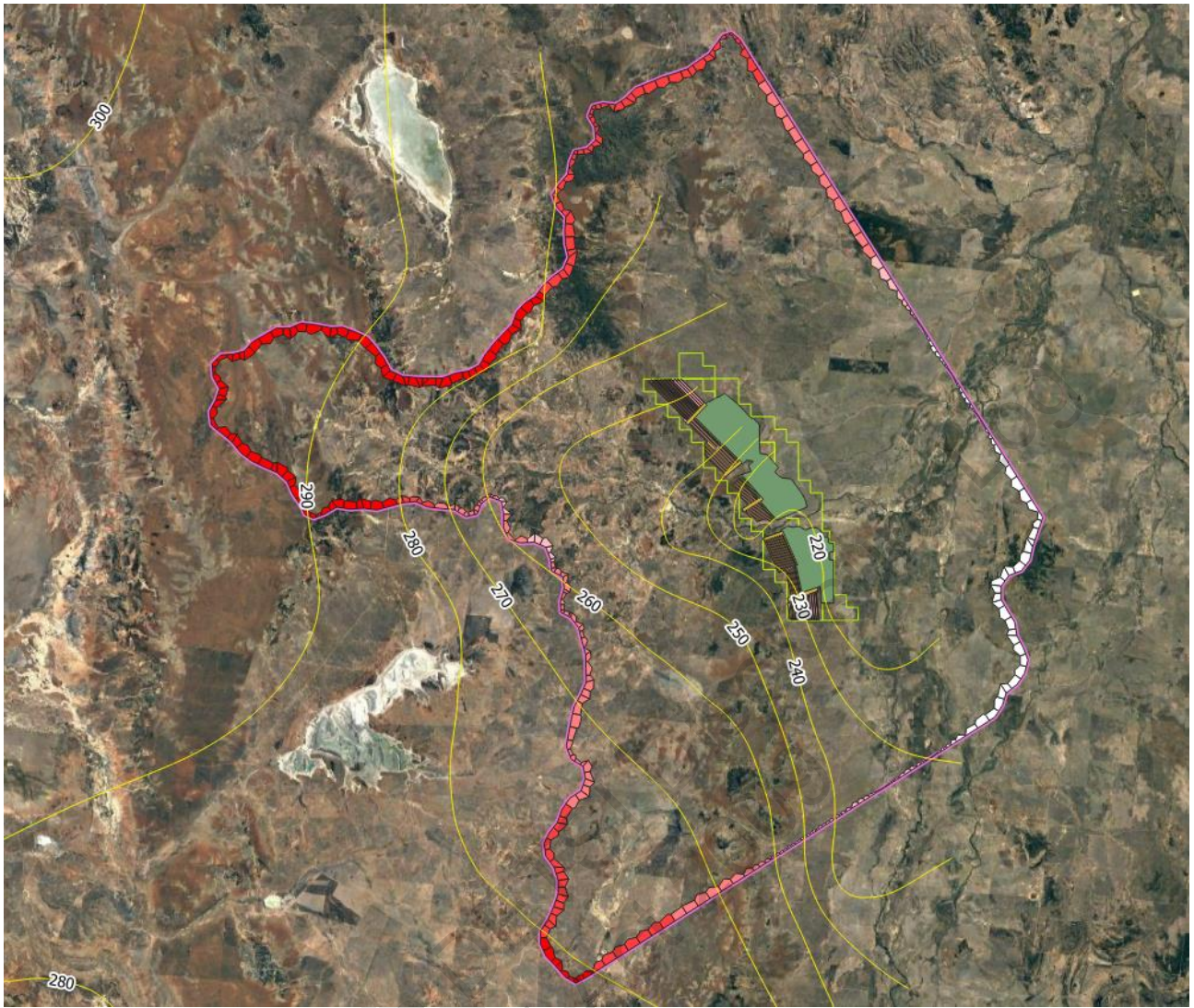


Figure 3.21 Modelled regional boundary conditions in D Coal and Colinlea Sandstone (coal seam underburden)

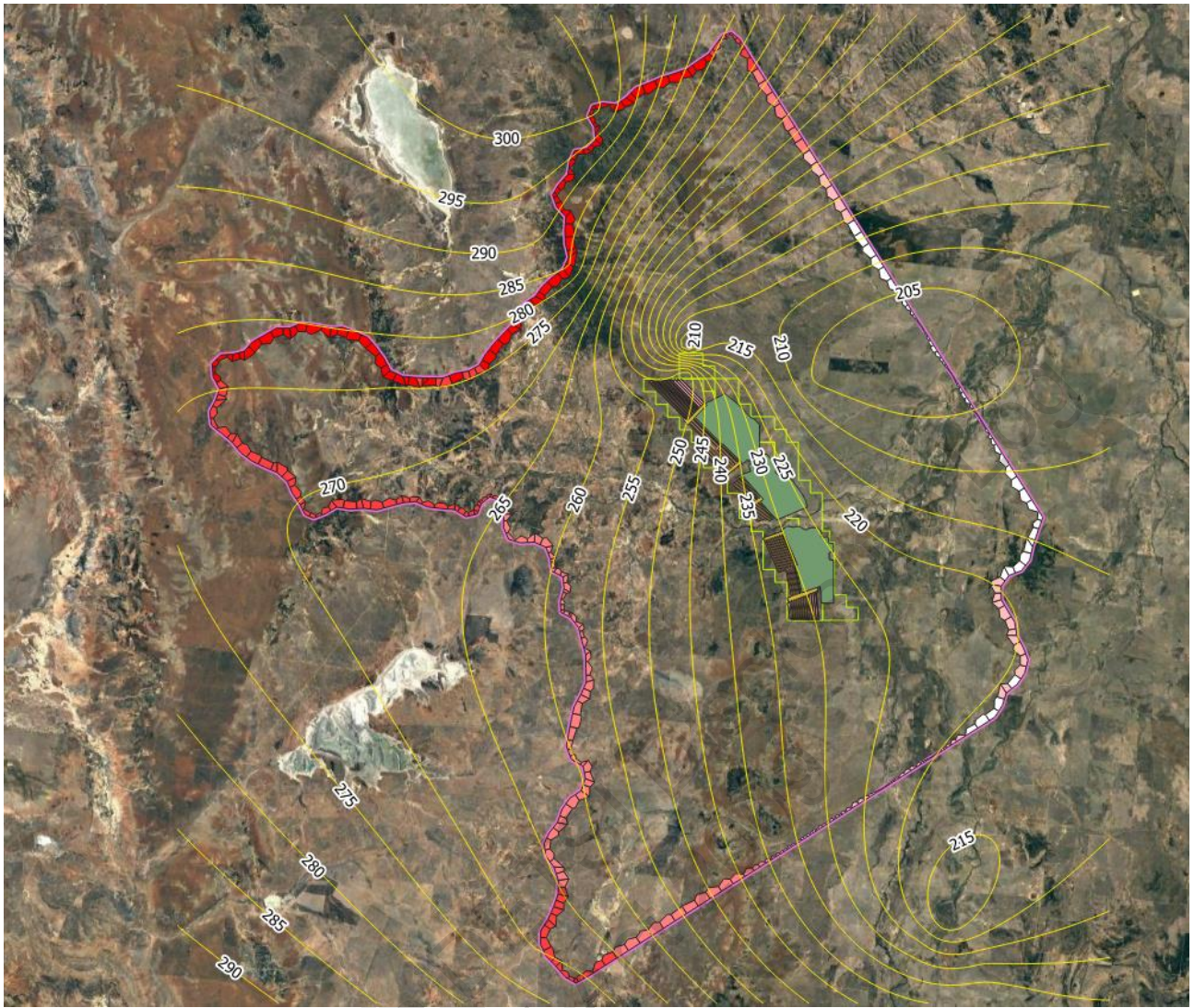


Figure 3.22 **Modelled regional boundary conditions in Joe Joe Group**

3.5.2 Watercourses

Major watercourses were simulated with river (RIV package) boundary conditions. The major systems identified in the model domain are as follows, and are presented in Figure 3.23:

- Belyando River (including a western breakout);
- Bimbah Creek;
- Carmichael River;
- Cattle Creek;
- Dunda Creek;
- Dyllingo Creek (including a northern breakout);
- North Creek; and
- Tomahawk Creek.

The watercourses were simulated with RIV package base set to topography, and time-varying stage above the river base. Wet season (December through March, simplified to Q1 for the history-matching period) stage elevation was set according to average measured river height, with the same values applied for each wet season (EMM 2022a). Dry season stage elevation was set to topography. The topography at each river boundary condition was extracted from the surface DEM, using zonal statistics to determine the lowest surface elevation in each river boundary condition model cell. River depths for the history-matching and prediction periods are presented in Table 3.3.

Conductance for the river boundary conditions was calculated with the following equation:

$$\text{Conductance} = \frac{\text{Hydraulic conductivity of river bed} \times \text{Cell area}}{\text{River bed thickness}}$$

Given an assumed riverbed thickness of 1 m and vertical hydraulic conductivity of 1 m/d, and a river area per cell of 1,500 m, starting riverbed conductance was applied as 1,500 m²/d. Given that the hydraulic properties of the riverbed sediments are not known, river boundary conductance was allowed to vary during the history-matching period (refer Section 4).

Setting river stage elevation equal to the river bottom during the dry season causes the boundary to behave in the same way as the drain (DRN) package; i.e. only allowing groundwater discharge at these cells. When the head in the aquifer is above the drain stage, water is removed from the boundary condition at a rate controlled by the conductance and hydraulic gradient. Conversely, discharge to the drain is zero when heads in the aquifer drop below the stage of the drain. During the wet season, water is allowed to enter and exit the model due to the river stage rising above topography, with groundwater inflow controlled by the conductance and driving head (i.e. saturated thickness of the river boundary condition).

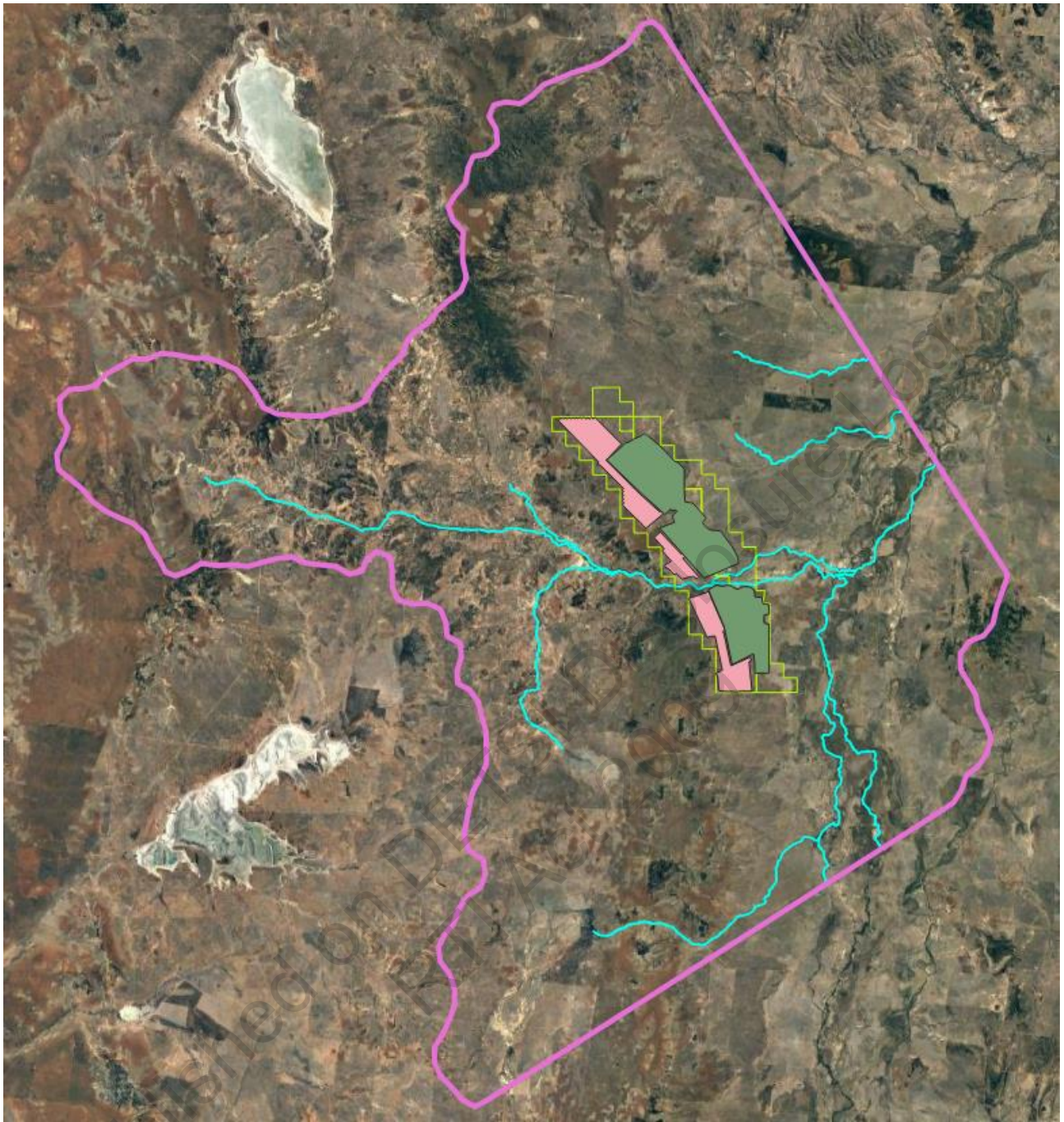


Figure 3.23 Modelled major watercourses

Table 3.3 **Modelled watercourse depths**

Watercourse ID	Depth in steady state stress period (m)	Wet season depth (m)	Dry season depth (m)
Belyando River	1.18	1.78	0
Belyando western breakout	0.59	0.89	0
Bimbah Creek	0	0	0
Carmichael River	0.30	0.70	0
Cattle Creek	0.15	0.35	0
Dunda Creek	0	0	0
Dyllingo Creek	0.15	0.35	0
Dyllingo northern breakout	0	0	0
North Creek	0	0	0
Tomahawk Creek	0	0	0

i Doongmabulla Springs

Springs comprising the Doongmabulla Spring Complex are simulated at mapped locations via drain (DRN) cells located within the Clematis Sandstone, consistent with the conceptualised source aquifer (EMM 2022a). The boundary stage elevations are set to the surveyed spring elevations. Boundary cell conductance was modified during the history-matching period to approximate the hydraulic separation between the Clematis Sandstone and ground surface. This in turn simplifies the model design for the spring features, removing the requirement to explicitly simulate and calibrate each spring conduit during the history-matching process.

The Doongmabulla Spring Complex is conceptualised to contain artesian springs with water sourced from the Clematis Sandstone, which discharges to surface and acts as a recharge mechanism for surficial sediments. To accommodate this, and consistent with the conceptualisation by EMM (2022a), selected drain cells were modified to drain return flow cells (DRT package), where modelled discharge via the drain cells was injected into model layer 1 at the same coordinates. Drain return flux was set equal to the drain outflow, with flux targets used to guide total drain flows.

ii Other springs

Other springs in the model domain include the following:

- Lignum;
- Mellaluka; and
- Storys.

Unlike the Doongmabulla Springs Complex, these springs are conceptualised as surface expression of watertable. These are simulated with the drain (DRN) package in model layer 15 (the highest active aquifer layer at these locations), with boundary stage elevations set to topography. Boundary cell conductance was modified during the history-matching process tied to springs in the DSC in lieu of flux estimates.

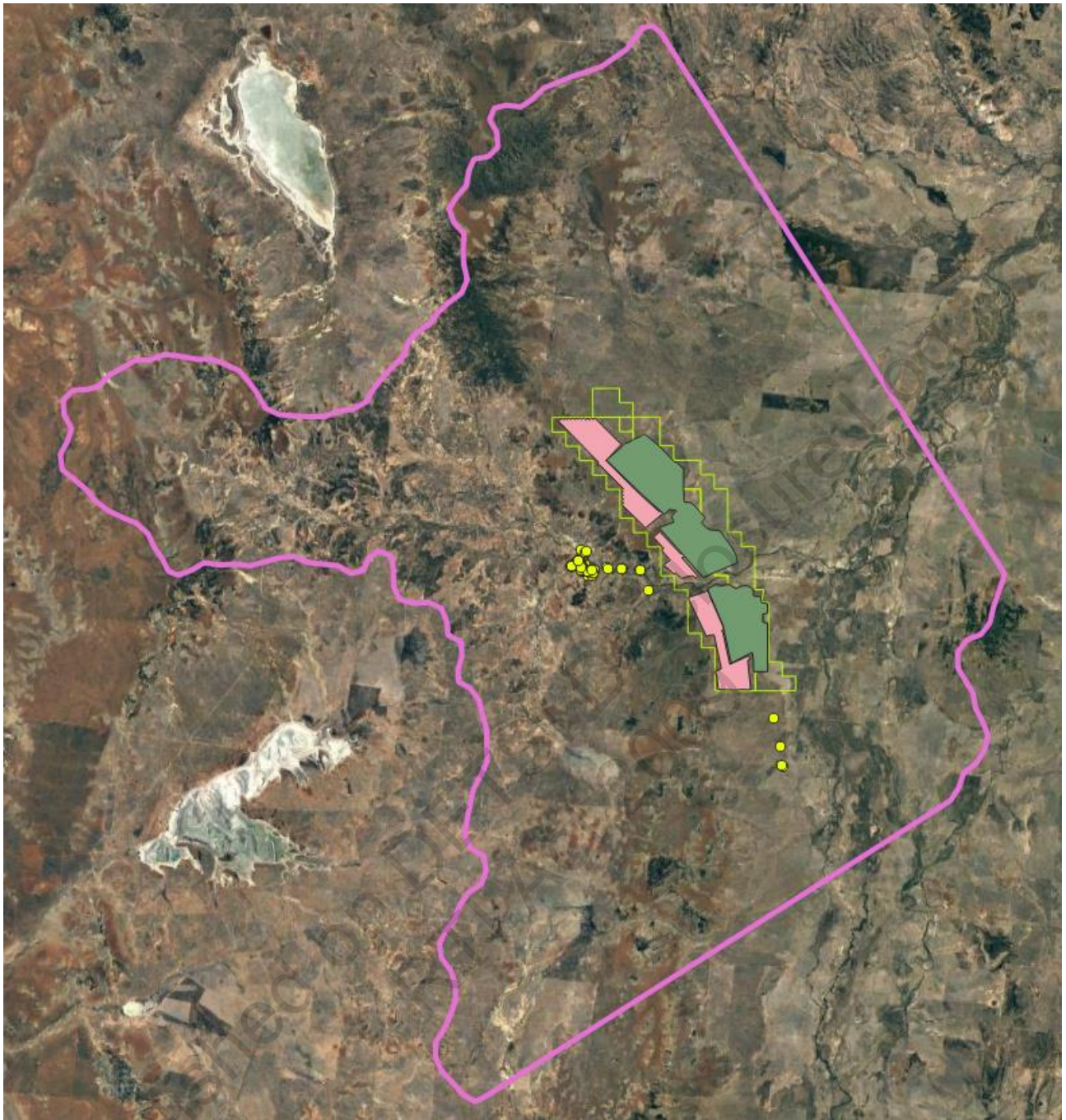


Figure 3.24 Modelled springs

3.5.3 Recharge

In accordance with the conceptual model, diffuse rainfall recharge to the watertable was modelled differently for each HSU based on its surface coverage, infiltration potential and seasonal influences. In addition, preferential recharge along flowing watercourses was also modelled implicitly for surficial alluvial deposits. The recharge package (RCH) was used to simulate these recharge processes, and the drain return flow (DRT) package was used to simulate alluvial recharge from artesian springs (discussed further in Section 3.5.2i).

Recharge was calculated per stress period based on measured data at Ulcanbah station (BoM station 036050), with a multiplier applied per outcropping HSU resulting in the following annual average rates:

- Quaternary alluvium: 0.009 mm/year;
- weathering zone: 0.002 mm/year;
- Tertiary and non-alluvial Quaternary deposits: 0.083 mm/year;
- Moolayember Formation: 0.003 mm/year;
- Clematis Sandstone / Warang Sandstone: 0.194 mm/year;
- Dunda Beds: 0.131 mm/year; and
- Rewan Formation: 0.098 mm/year.

Recharge was allowed to vary during the history-matching period, discussed further in Section 4. Modelled recharge zones are presented in Figure 3.25, aligned with outcropping HSUs.

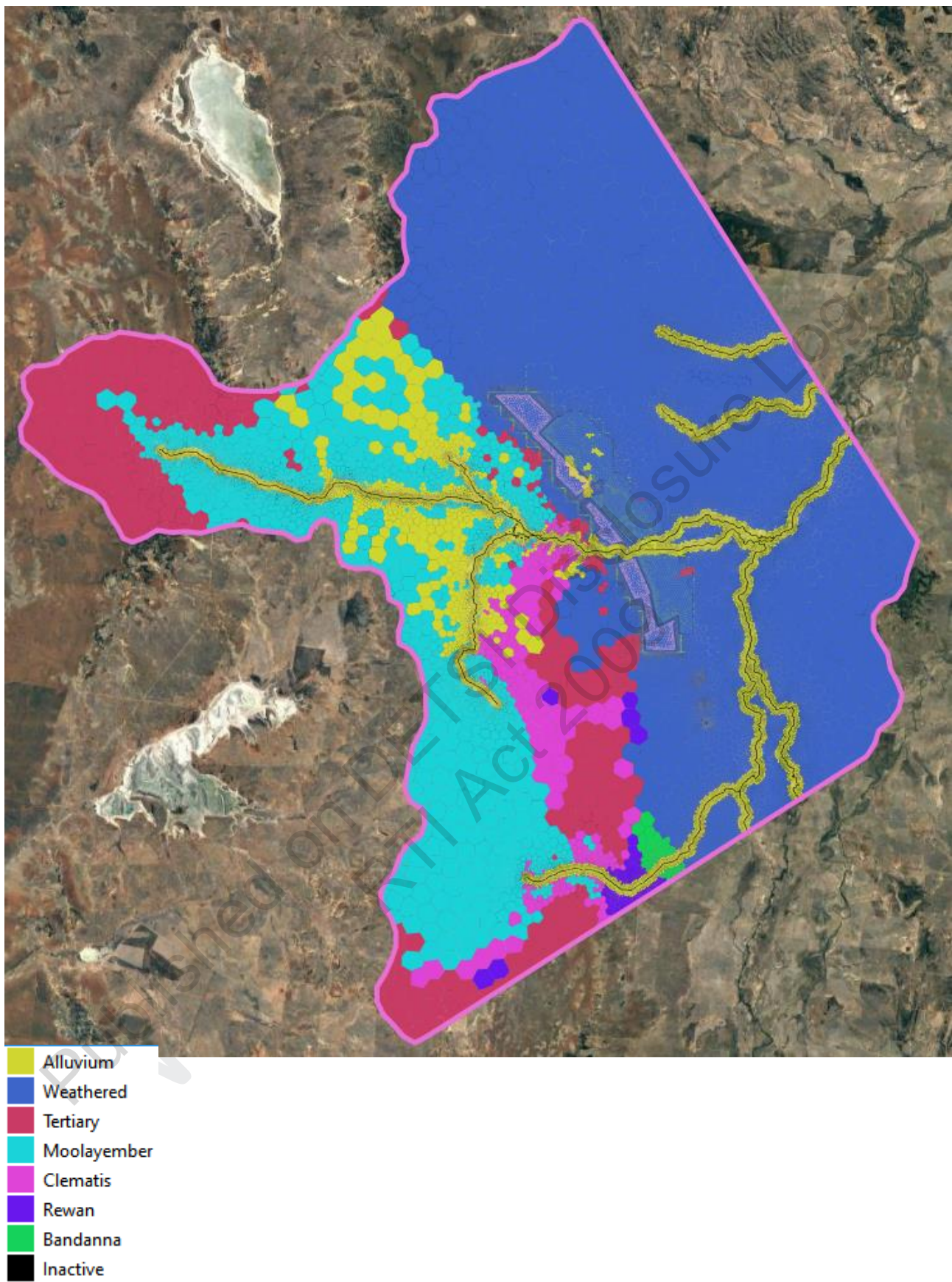


Figure 3.25 Modelled recharge zones based on outcropping HSU

History-matching stress periods incorporate actual measured rainfall. Predictive stress periods (refer Table 3.2) utilise average measured rainfall for wet/dry seasons, and the long-term stress periods utilise the average of all measured rainfall data. Rainfall data discretised by stress period duration are presented in Figure 3.26. The shorter duration of stress periods from August 2019 to April 2022 allows for more detail to be included, though the averaging over a month reduces the modelled influence of individual rainfall events.

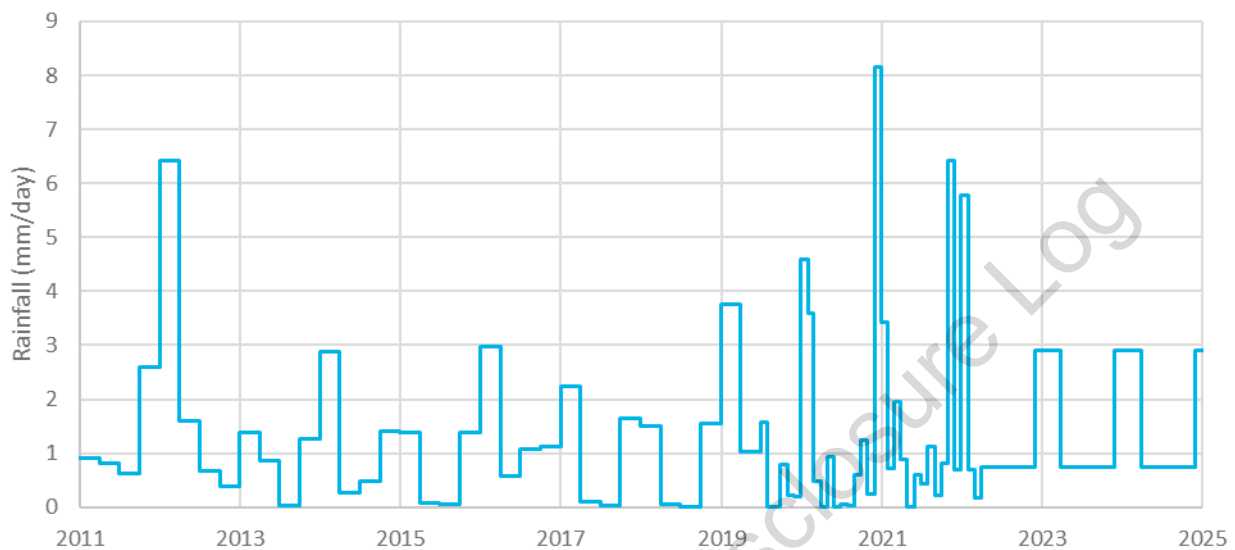


Figure 3.26 Time series of rainfall discretised by model stress periods

3.5.4 Evapotranspiration

The MODFLOW evapotranspiration (EVT) package is employed to represent evapotranspiration across the model domain. Maximum potential evapotranspiration is set per model stress period in accordance with BoM climate maps (BoM 2022), based on 30-year averaged data with equating to an average rate of 4.4 mm/day.

Based on the relatively sparse vegetation in the study area, review of aerial photography, and assessment of land use prepared by BRS (2010), an evapotranspiration extinction depth of 1.5 m has been applied for the model domain. This evapotranspiration extinction depth is consistent with Shah et al. (2007) for grass cover on sandy soil. A second evapotranspiration zone is active adjacent to surface water features to represent increased vegetation cover, with an extinction depth of 6 m. Evapotranspiration is not applied to surface water features.

3.5.5 Mining activities

One predictive scenario was developed based on planned mining developments to allow for assessment of absolute impacts. The mine plan was provided by Bravus, discretised into 13 stages and from 2020 to 2075. Detail of the mine plan is presented in Table 3.4 showing open cut pits (OC) B through F, and underground areas (UG) 1 through 5. The mine plan is similar to the plan presented in the SEIS (GHD 2013a) with some changes to staging, notably delaying commencement of the underground mine by 10 years.

Table 3.4 Summary of mine plan

Year	OC B	OC C	OC DE	OC G	OC F	UG 1	UG 2	UG 3	UG 4	UG 5
2020			Active							
2021			Active							
2022			Active							

Table 3.4 **Summary of mine plan**

Year	OC B	OC C	OC DE	OC G	OC F	UG 1	UG 2	UG 3	UG 4	UG 5
2023			Active							
2024			Active							
2029		Active	Active							
2034	Active	Active	Active			Active				
2039	Active	Active	Active	Active	Active	Active				
2044	Active	Active	Active	Active	Active	Active			Active	Active
2049	Active	Active	Active	Active	Active	Active			Active	Active
2055	Active	Active	Active	Active	Active	Active		Active	Active	Active
2065	Active	Active	Active	Active	Active	Active	Active	Active	Active	Active
2075	Active	Active	Active	Active	Active	Active	Active	Active	Active	Active

i **Production bores**

The MODFLOW well (WEL) package is employed to simulate groundwater abstraction from mine dewatering bores. Measured groundwater abstraction for each bore is incorporated in the monthly stress periods in the history-matching period from August 2019 to March 2022 (Table 3.2). Predicted mine dewatering is simulated via drain boundary cells (refer Section ii), and as such no groundwater abstraction bores are active in the predictive period.

Modelled production bores are presented in Figure 3.28, and measured monthly abstraction rates are presented per bore and per screened HSU in Figure 3.29.

ii **Mine voids**

Groundwater removed from open cut and underground mine voids is simulated using the MODFLOW drain (DRN) package. This represents removal of any groundwater entrained in excavated material and groundwater inflows to the excavated voids. The mine progression is simulated in accordance with the provided staged mine plan (refer Appendix D) for the predictive period, with boundary cells activated at the first stress period corresponding to the numbered mine plan stage. Drain conductance is set at a suitably high value to ensure full dewatering of model cells to the assigned drain stage (1,000 m²/d). The modelled DRN cells at the end of mining are presented in Figure 3.30.

Modelled base elevations for open cut pits and underground mines are presented in Figure 3.31 and Figure 3.32 respectively.

Prediction stress periods (refer Table 3.2) present a higher temporal resolution than is available for the mine plan, to preserve the dynamic equilibrium of the groundwater system between the wet and dry seasons. Activation of mine dewatering DRN cells at the start of these seasonal stress periods results in rapid modelled dewatering and associated drawdown. This is accounted for in post-processing of the modelled water balance (Section 5.2) by averaging DRN flux across all stress periods corresponding to a single mine stage and is considered conservative in predicting drawdown impacts (Section 5.3).

iii Mining-induced property changes

Longwall panel mining of the coal seams is conceptualised to induce fracturing above mined panels and is expected to result in enhanced hydraulic conductivity. The time-varying materials (TVM) package is applied in model cells above underground mine cells, increasing hydraulic conductivity following mining. Two approaches were prepared, following GHD (2013b) and Merrick (2021), to allow for direct comparison against the existing groundwater model and updated for current estimates.

The fracturing property changes adopted by GHD (2013) include modification of hydraulic conductivity for cells within 160 m of the top of mined cells, with no fracturing above the top of the Rewan Formation. Hydraulic conductivity values are increased by a factor of 50 for cells within 75 m of the mined cells, and a factor of 10 for the remaining 75 m.

Merrick (2021) calculated fracturing heights above mine cells, with an average value of 230 m. Associated hydraulic conductivity increases are calculated using a ramp function, detailed in Merrick (2017) and presented in Figure 3.27.

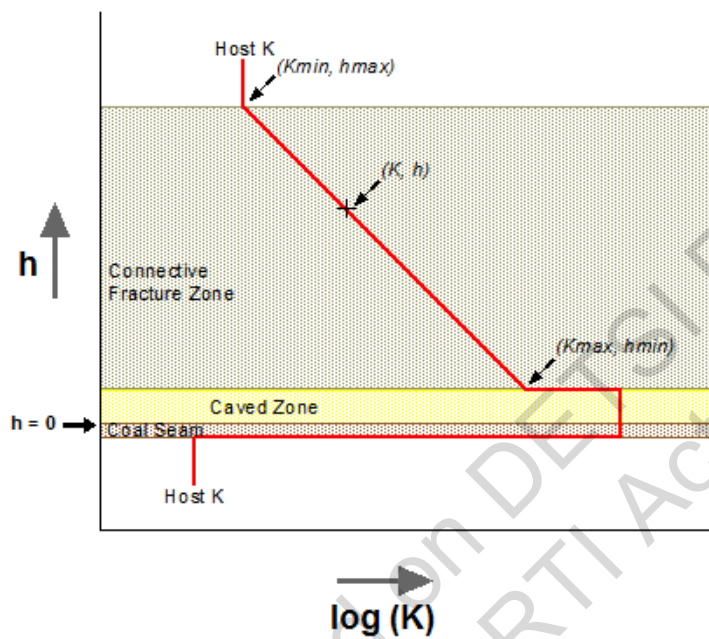


Figure 3.27 Ramp function parameters

Hydraulic conductivity in the connective fracture zone is calculated by:

$$K = 10^{\left(\log(K_{max}) - \frac{\log(K_{max}) - \log(K_{min})}{h_{max} - h_{min}}(h - h_{min})\right)}$$

Parameters for the updated model are as follows:

- $K_{max} = 5 \text{ m/d}$;
- K_{min} = background (calibrated) hydraulic conductivity;
- $h_{max} = 230 \text{ m}$; and
- $h_{min} = 0 \text{ m}$ (assuming caving to top of coal seam).

No fracturing was assigned to model layers 1 to 3 due to the assumption of self-sealing clays (alluvium, weathering, and Tertiary sediments).

At the end of mining, modelled drain cells corresponding to dewatering of mine voids are deactivated. At the cessation of mining, the open cut pit is planned to be backfilled as follows:

- Pits C, E, and F are located closer to the Carmichael River and thus are required to be backfilled to the top of the AB Coal seam
- All other pits are located further away from Carmichael River and thus are only required to be backfilled to the top of the D Coal seam.

The post-mining open cut pit depth is presented in Figure 3.33 and rehabilitation and backfill is simulated to commence at the end of mining. These pit depths and the pre-mining watertable elevation in the vicinity of the mine indicate potential for a pit lake to form. The open cut pit and associated stresses are simulated following mining using three packages:

- the time-varying materials (TVM) package is applied at model nodes within the residual open cut pit void, converting the material properties to that of a 'void' at the cessation of mining. This package assigns multiplier values to horizontal and vertical hydraulic conductivities, specific yield, and specific storage. The final values are 1,000 m/d for hydraulic conductivity, 100% for specific yield, and specific storage 1.3×10^{-5} m/d;
- the connected linear node (CLN) package is applied across the footprint of the open cut pit void, with a setup designed to mimic surface water evaporation but with greater numerical stability than the ETS package. One CLN 'well' was assigned per node, with top elevation set at pre-mining topography and bottom elevation set at the base of the backfilled pit. Abstraction was activated at each of these wells, with rate scaled by cell area such that the maximum rate of water removal is 3.1 mm/day (a 30% reduction from the pan evaporation rate of 4.4 mm/day, consistent with Fandrich (2016)). If the water level drops below the bottom of a well, no water is abstracted, mimicking evaporation; and
- recharge from rainfall (RCH) is increased over the pit footprint to 100% of rainfall (1.5 mm/d) for the post-mining period, where rainfall can directly recharge the potential pit lake surface.

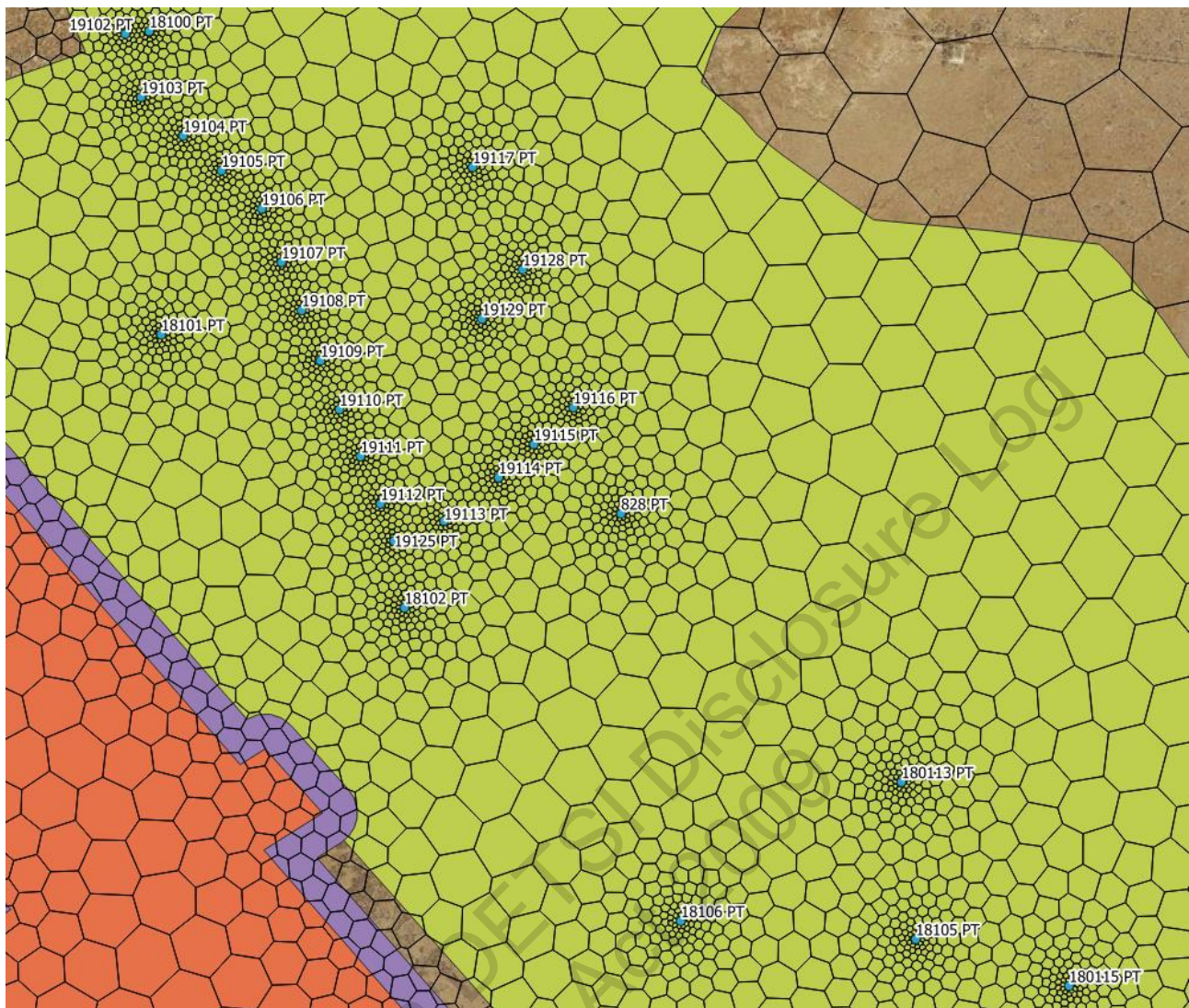


Figure 3.28 **Modelled production bores**

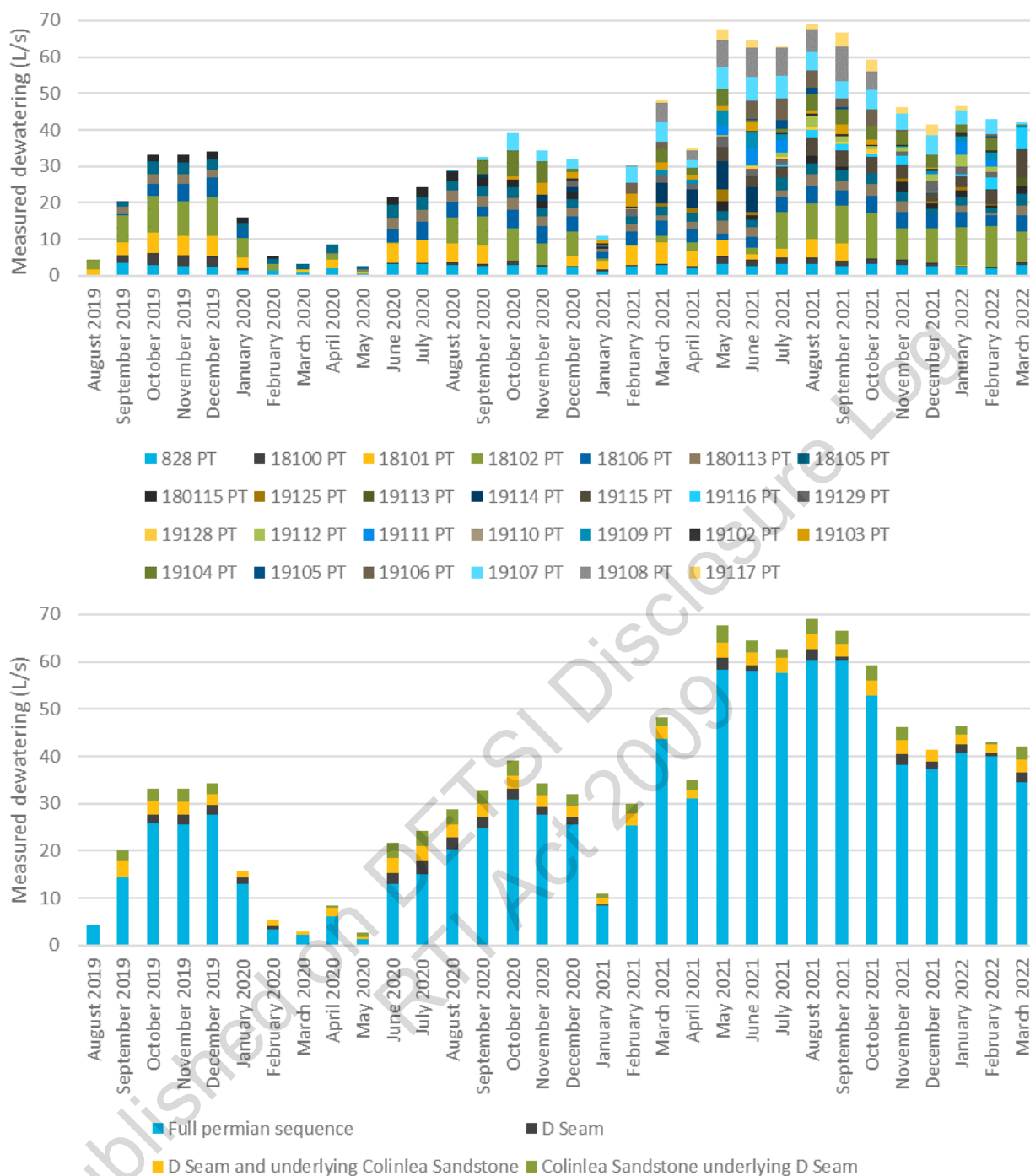


Figure 3.29 Measured production bore dewatering rates

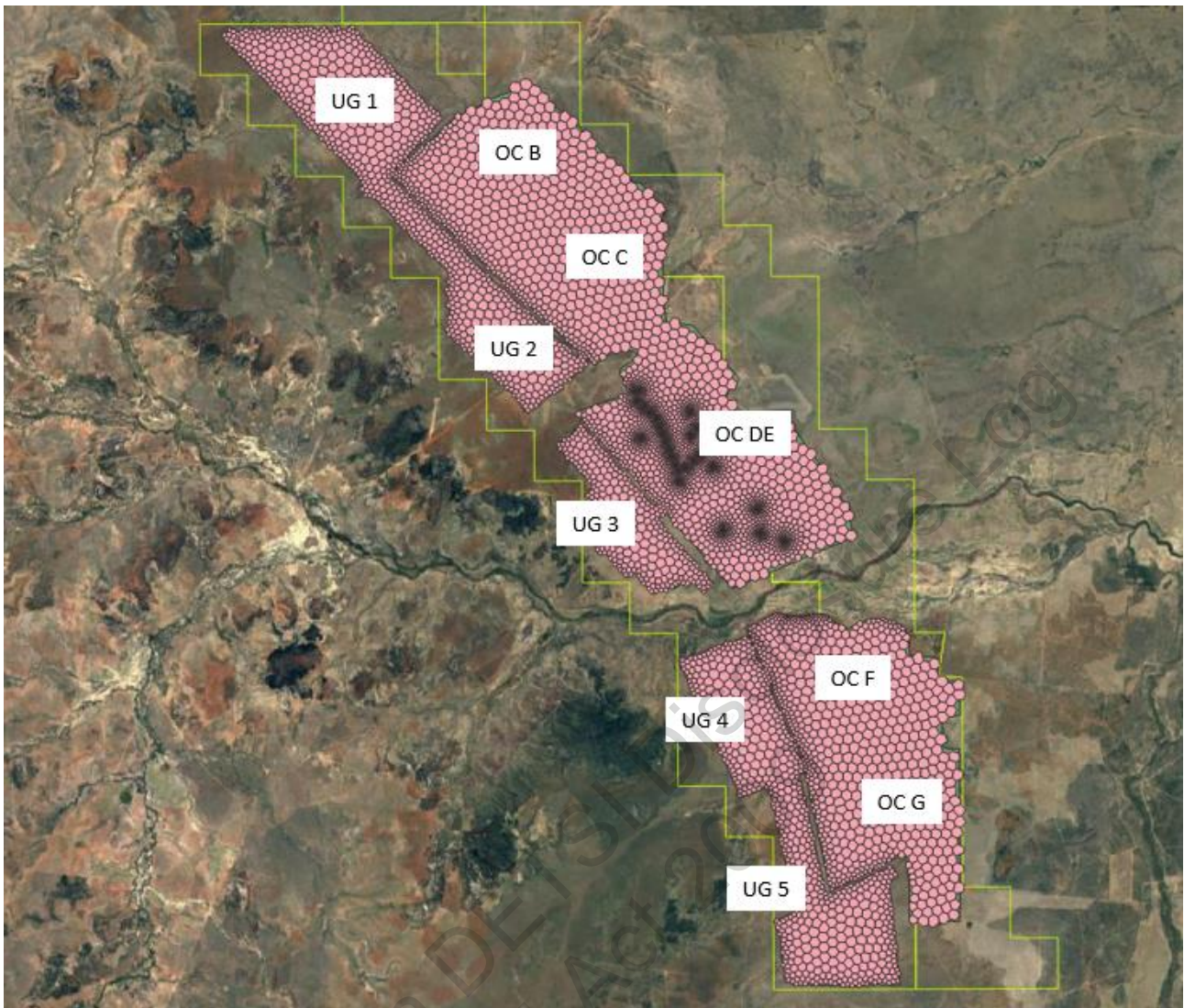


Figure 3.30 Modelled drain boundary conditions at the end of mining

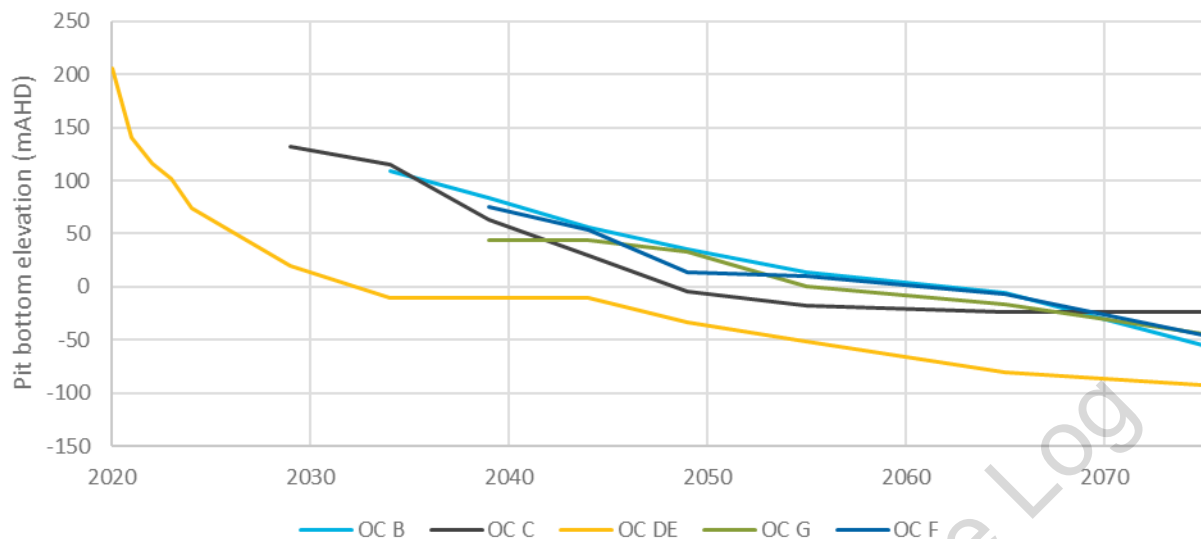


Figure 3.31 Open cut pit bottom elevations

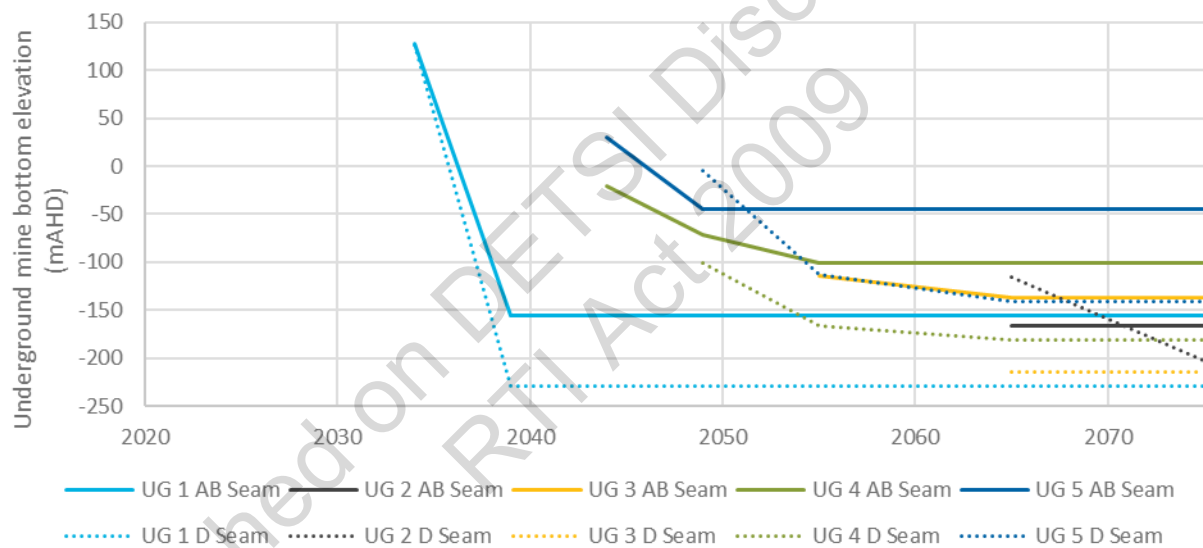


Figure 3.32 Underground mine bottom elevations

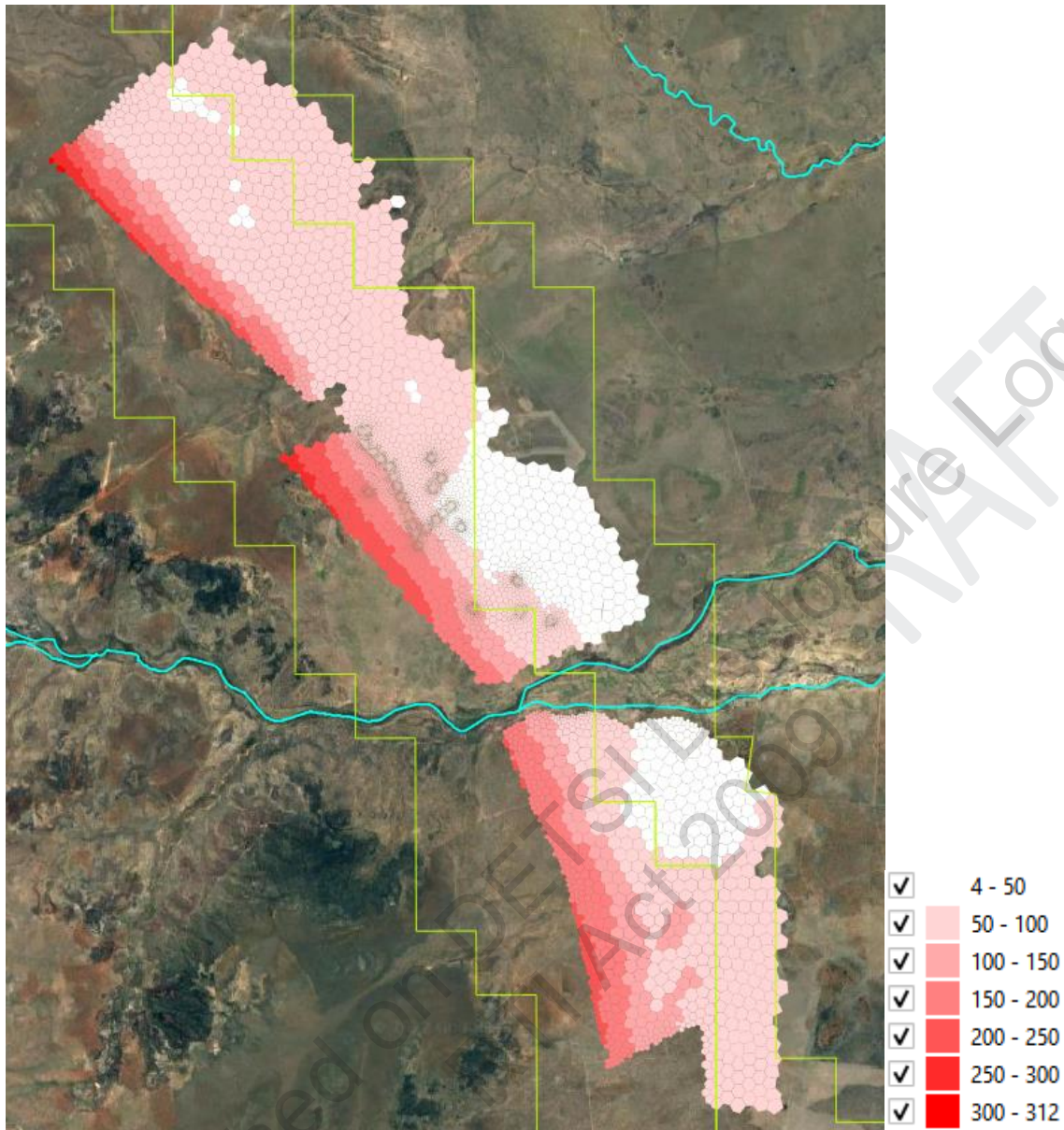


Figure 3.33 Modelled post-mining pit void depth

4 History-matching

4.1 Approach

A combination of manual and automated approaches were employed during the history-matching process using PESTPP-IES (White., 2018, White et al., 2019) This code optimises an ensemble of random model parameter realisations on an iterative basis, making an estimate of the Jacobian matrix (which is used by the traditional PEST code) using the ensemble of parameters and observations for each parameter upgrade iteration.

History-matching was undertaken using hydraulic head data from pre-mining conditions and during mining, employing bores impacted by mine dewatering. Spring flux targets were included to ensure consistency between water balance modelling and the numerical groundwater flow model.

Initially, the model was calibrated with homogeneous parameters, using a single value for each hydraulic property per HSU. This approach was aimed at providing a computationally efficient means to arrive at starting parameters that provided a model-wide fit to hydraulic head and flux data, to use as initial parameter value estimates for subsequent highly parameterised history-matching.

4.1.1 Targets

The model was history-matched using both hydraulic head and head-change targets, to obtain model parameterisation consistent with both pre-development and impacted conditions. Hydraulic head targets were used at the time of measurement, rather than steady state, as the unimpacted system is conceptualised to exist in a dynamic equilibrium associated with seasonal and climatic patterns. Automated history-matching software then attempts to match both absolute groundwater level and dynamics, both from climatic stresses and mine dewatering. Groundwater measurements were taken from manual readings and loggers; these have been separated into separate target groups. Logger data were resampled to monthly measurements to reduce the volume of target data.

Flux targets at Doongmabulla springs were defined for the steady-state stress period, as discharge estimates from water balance modelling (EMM, 2022b) do not incorporate seasonality or longer-term climatic influences. This is consistent with the conceptualisation that the Doongmabulla springs are sourced from the deeper Clematis Sandstone, and therefore exhibit less influence from climate.

A total of 11,443 history-matching targets were employed. These were subdivided into the following groups:

- 239 hydraulic head targets, grouped by HSU;
- 11,202 head-change targets, grouped by HSU; and
- 2 flux targets.

PEST operates with the goal of minimising a least-squares objective function, defined as the sum of squared weighted differences between measurements and corresponding model outputs (known as residuals). Doherty (2016) defines the objective function as:

$$\varphi = \sum (w_i r_i)^2$$

where r is the calculated residual, and w is a unitless statistical weighting.

A weighting scheme was adopted to ensure that each measurement group effectively contributed to the objective function, and likewise that monitoring locations with high volumes of data did not overly control the history-matching process. Statistical contributions to the objective function of the uncalibrated model were calculated, and weights modified such that each target group contributed the same value to the starting objective function. Each measurement within a target group therefore had the same weight applied. Weights of hydraulic head

targets were increased by a factor of $\sqrt{2}$ to double the relative computational effort towards matching absolute groundwater levels.

Measurement noise was not included in the PESTPP-IES control file.

The locations of monitoring bores used for history-matching targets are presented in Figure 4.1, categorised by HSU.

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Figure 4.1 History-matching target bores and springs

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4.1.2 Stresses

Hydrogeological stresses applied during the history-matching period are detailed in Section 3.5. These are:

- seasonal rainfall-derived recharge;
- seasonal leakage from surface water features; and
- pumping via bores for mine dewatering.

As described in EMM (2022a), the groundwater monitoring dataset exhibits responses to both climatic and mining stresses, with variable magnitude of impact depending on location.

4.1.3 Parameterisation

i Pilot points

The algorithm for calculation of the Jacobian matrix via PESTPP-IES is extremely efficient when compared to other versions of PEST, and as such there is no effective limit on the number of pilot points that can be incorporated in the history-matching assessment. A triangulation algorithm was employed to place pilot points between targets (including pumping bores), and additional pilot points were placed at regular 5 km spacing. A total of 7,740 pilot points were used per hydraulic parameter (horizontal and vertical hydraulic conductivity, specific storage, specific yield), resulting in 30,960 pilot point parameters. Additional parameters for spring (Drain) conductance (Section 3.5.2i) and recharge zones (Section 3.5.3) were included, resulting in a total of 30,976 parameters.

ii Initial (prior) parameter values

PESTPP-IES requires the user to supply statistical characteristics of the prior parameter values and allowable ranges; this takes the form of either independent standard deviations around the expected (initial / mean) value per parameter, or parameter covariances where for example there may be spatial correlation between parameters (e.g. between pilot points used to interpolate parameters to the model mesh for a given layer). These characteristics are used by PESTPP-IES when drawing stochastic parameter realisations at the start of each iteration.

Parameters were not assumed to be spatially dependent (correlated), and parameter standard deviations were calculated from the log-transformed range defined in the PESTPP-IES control file, where the upper and lower bounds (as per EMM (2022a)) are taken to represent the 95% confidence interval. As mentioned above, parameters varied as part of the history-matching process include:

- all HSU hydraulic parameters (horizontal and vertical hydraulic conductivity, specific storage, specific yield);
- all spring (Drain) conductance parameters; and
- all groundwater recharge rate zone parameters.

A 500-realisation ensemble of parameter values was developed as the 'prior' parameter ensemble, and several iterations were employed using PESTPP-IES to develop a parameter field minimising the error to measurements. Following model review, a final 'posterior' ensemble of parameter realisations was developed, with a Gaussian distribution centred on base realisation pilot point values where one standard deviation is equal to one order of magnitude. This ensemble was used towards predictive uncertainty analysis (Section 5.3).

iii History-matched (posterior) parameter values

This section describes the 'base case' or best estimate achieved by PESTPP-IES from all 500 history-matched model realisations, along with accepted uncertainty parameter field realisations (discussed further in Section 4.2.1). These parameters include hydraulic conductivity (Kh and Kv) distributions, storage properties, as well as parameters applied to modelled boundary conditions (i.e. recharge and drain (spring) conductance). The focus here is on discussion of the key aquifer and aquitard units (Clematis, Rewan, and coal seams), with minimal reference to the properties of the other HSUs including shallower sediments and deeper Permian units.

a Layer 5: Clematis Sandstone aquifer

The Clematis Sandstone is conceptualised as the source aquifer of the Doongmabulla springs, and is a key unit for estimating spring impacts. The pilot point parameter frequency distribution for the Clematis Sandstone is presented in Figure 4.2, with frequency for the base realisation on the secondary vertical axis. This shows the variation within the unit for the base realisation, and the combined Gaussian distributions of uncertainty realisations centred on each of the base pilot point values. The majority of values lie between 0.1 and 1 m/day, which is consistent with the hydrogeological conceptual model (EMM 2022a).

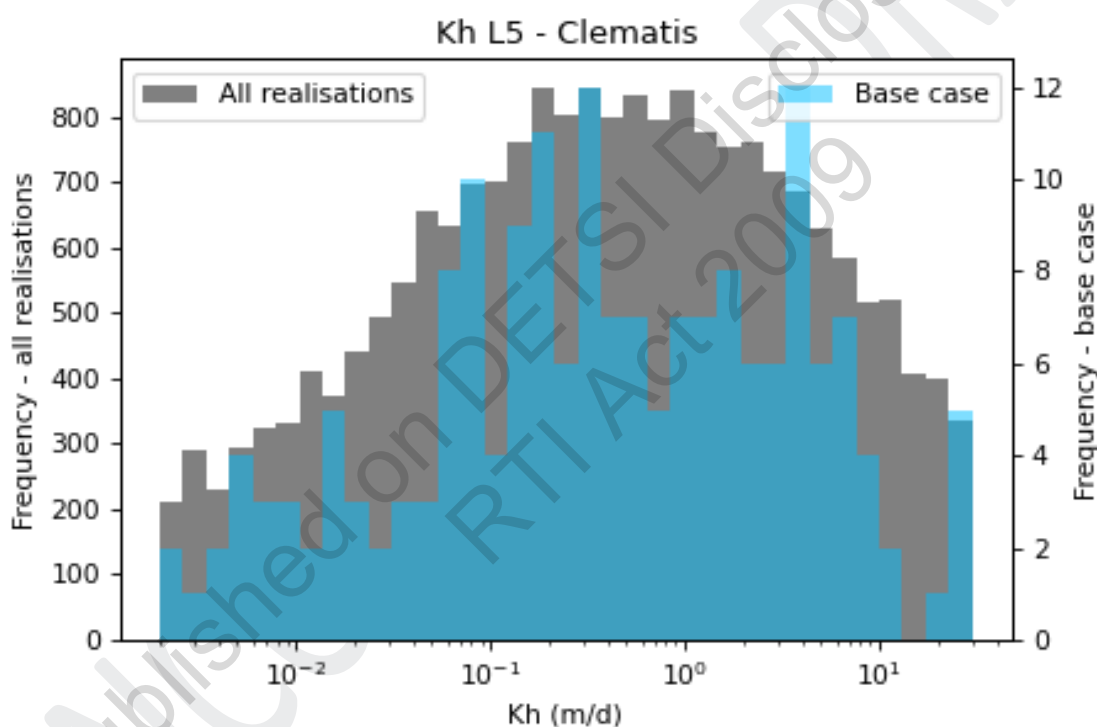


Figure 4.2 Horizontal hydraulic conductivity pilot point parameter frequency distribution for Clematis Sandstone across base realisation and uncertainty ensemble

The spatial distribution of modelled horizontal hydraulic conductivity in the Clematis Sandstone for the base realisation is presented in Figure 4.3. Hydraulic conductivity is generally higher north of the Carmichael River, with values typically higher than 0.1 m/day. The Clematis Sandstone south of the Carmichael River is simulated with lower hydraulic conductivities, below 0.1 m/day.

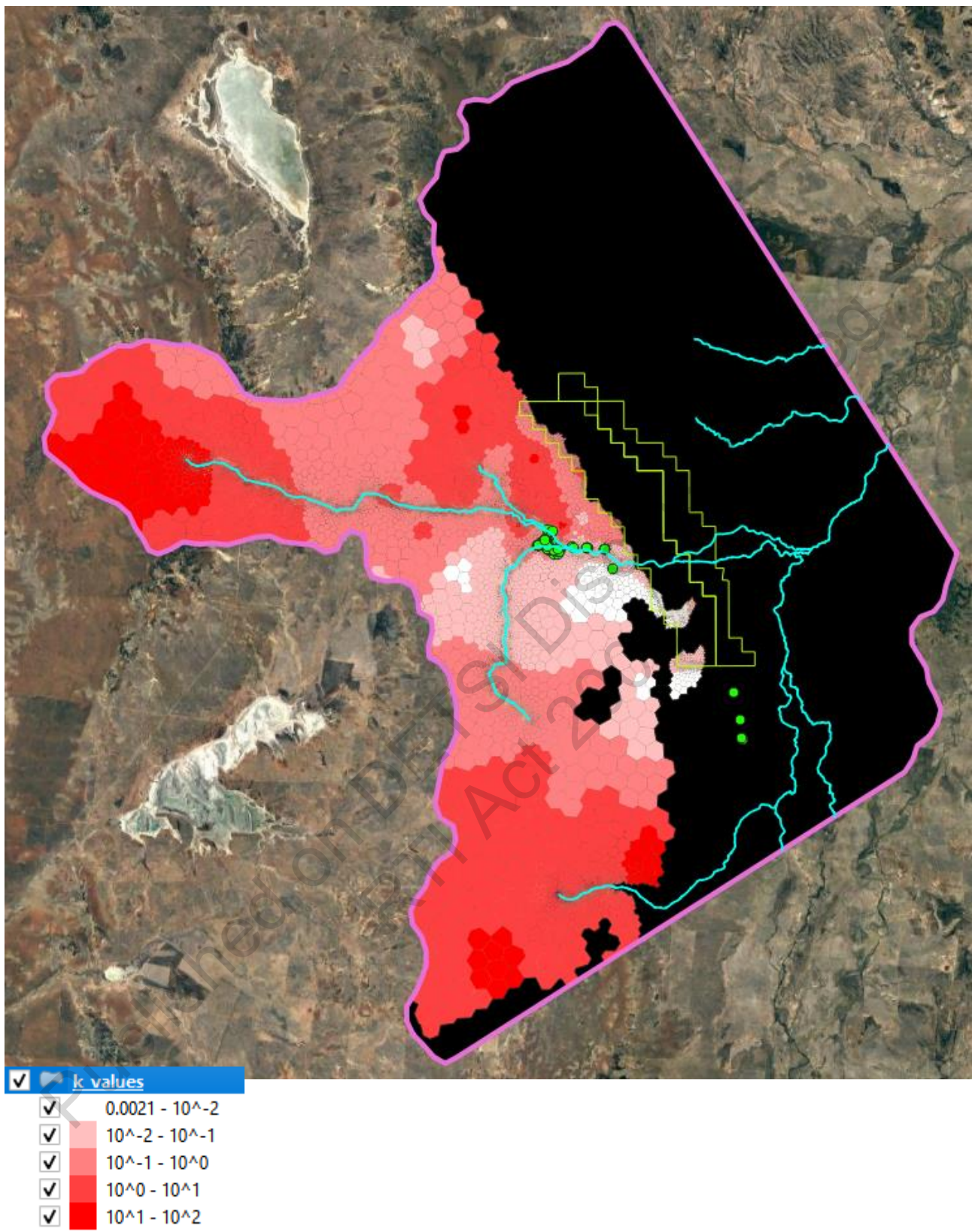


Figure 4.3 Base realisation modelled horizontal hydraulic conductivity in Clematis Sandstone

b Layers 7 and 8: Rewan Formation

The Rewan Formation is the primary aquitard separating the Doongmabulla springs and the mined coal seams. This unit is subdivided into two model layers of equal thickness, to allow for additional discretisation of hydraulic conductivity with depth. Vertical hydraulic conductivity pilot point parameter frequency distributions for the upper and lower Rewan Formation are presented in Figure 4.4 and Figure 4.5 respectively. Typical modelled vertical hydraulic conductivity values for the Rewan Formation are between 1×10^{-6} and 1×10^{-5} m/day for the upper profile and around 1×10^{-7} m/day for the lower profile. In addition to this, a number of pilot points are at the lower bound assigned to the lower Rewan Formation; 2×10^{-9} m/day.

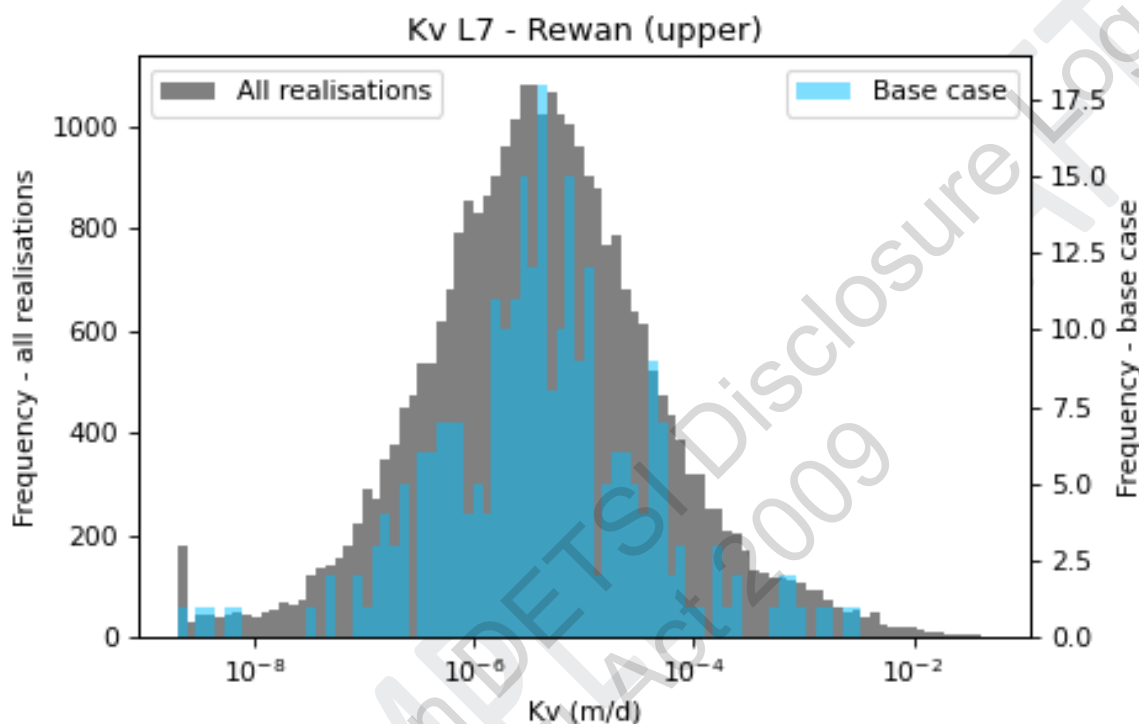


Figure 4.4 Vertical hydraulic conductivity pilot point parameter frequency distribution for upper Rewan Formation across base realisation and uncertainty ensemble

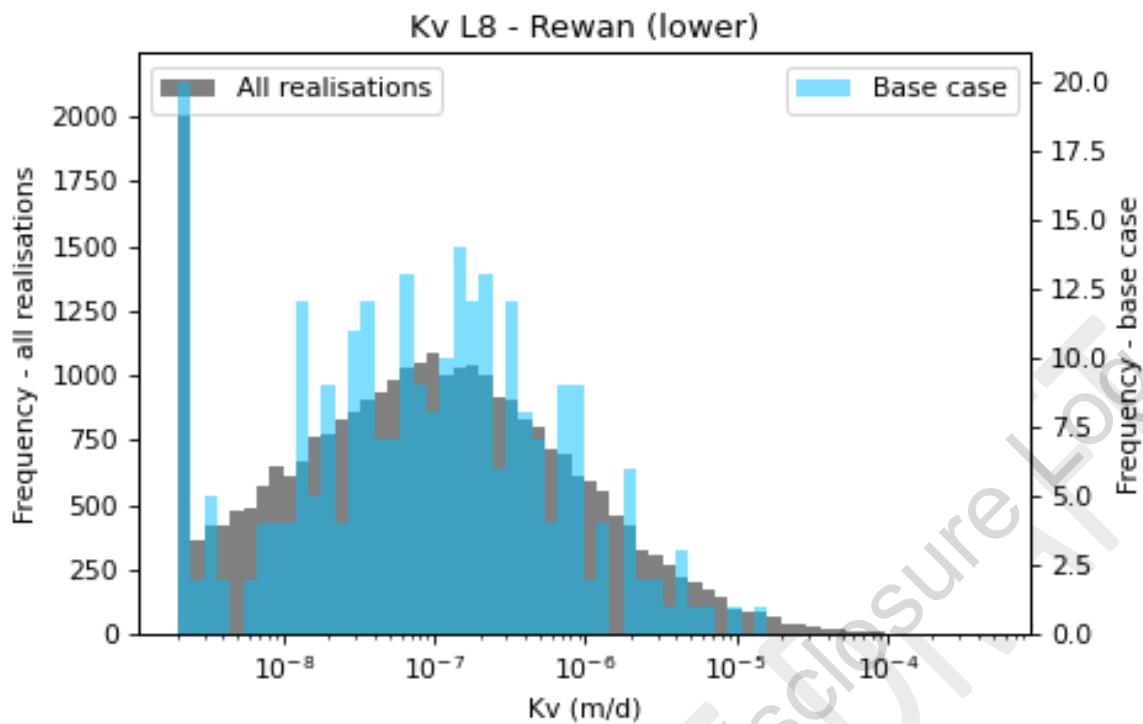


Figure 4.5 Vertical hydraulic conductivity pilot point parameter frequency distribution for lower Rewan Formation across base realisation and uncertainty ensemble

The spatial distribution of modelled vertical hydraulic conductivity in the upper and lower Rewan Formation is presented in Figure 4.6 and Figure 4.7 respectively. Similar to the Clematis Sandstone, an area of lower hydraulic conductivity is simulated south of the Carmichael River, towards the southern end of the ML, with areas of higher conductivity north of the Carmichael River.

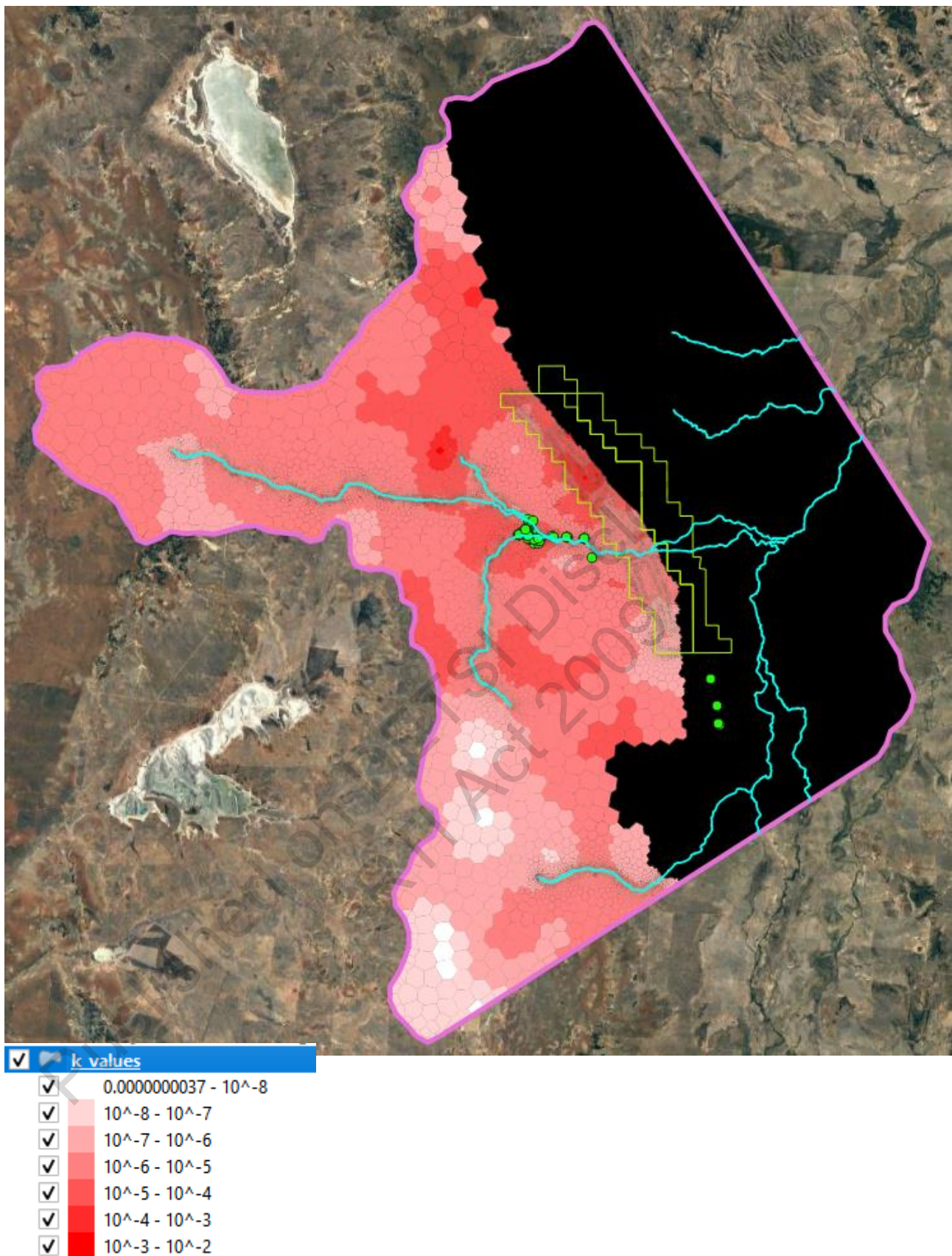


Figure 4.6 Base realisation modelled vertical hydraulic conductivity in upper Rewan Formation

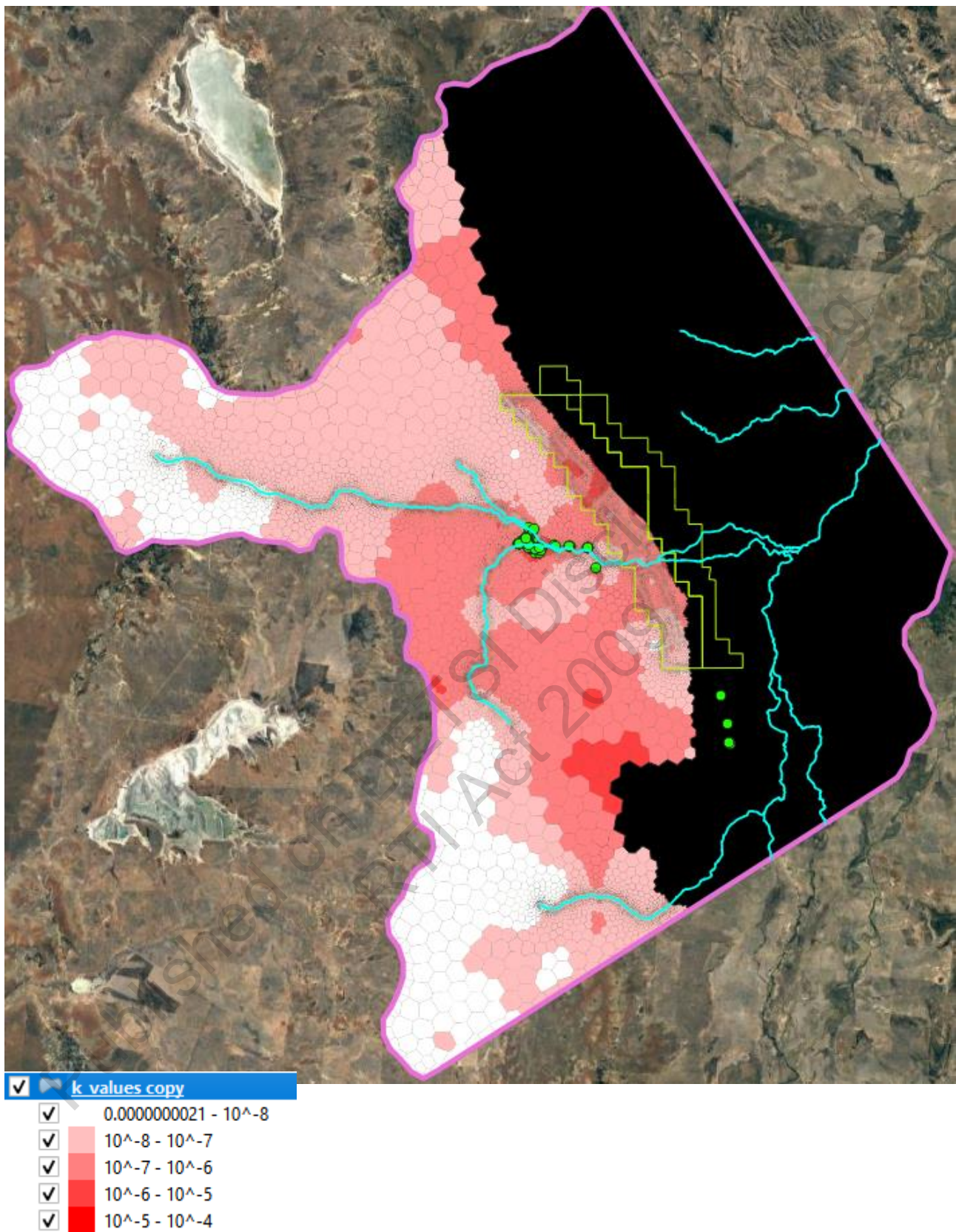


Figure 4.7 Base realisation modelled vertical hydraulic conductivity in lower Rewan Formation

Modelled horizontal hydraulic conductivity pilot point parameter frequency distributions for the AB and D coal seams are presented in Figure 4.8 and Figure 4.9 respectively. The AB seam is simulated with a relatively even distribution, with peak around 1-2 m/day. The D seam is simulated with a much lower hydraulic conductivity, with PEST tending to the lower end of conceptual bounds, 1×10^{-2} m/day.

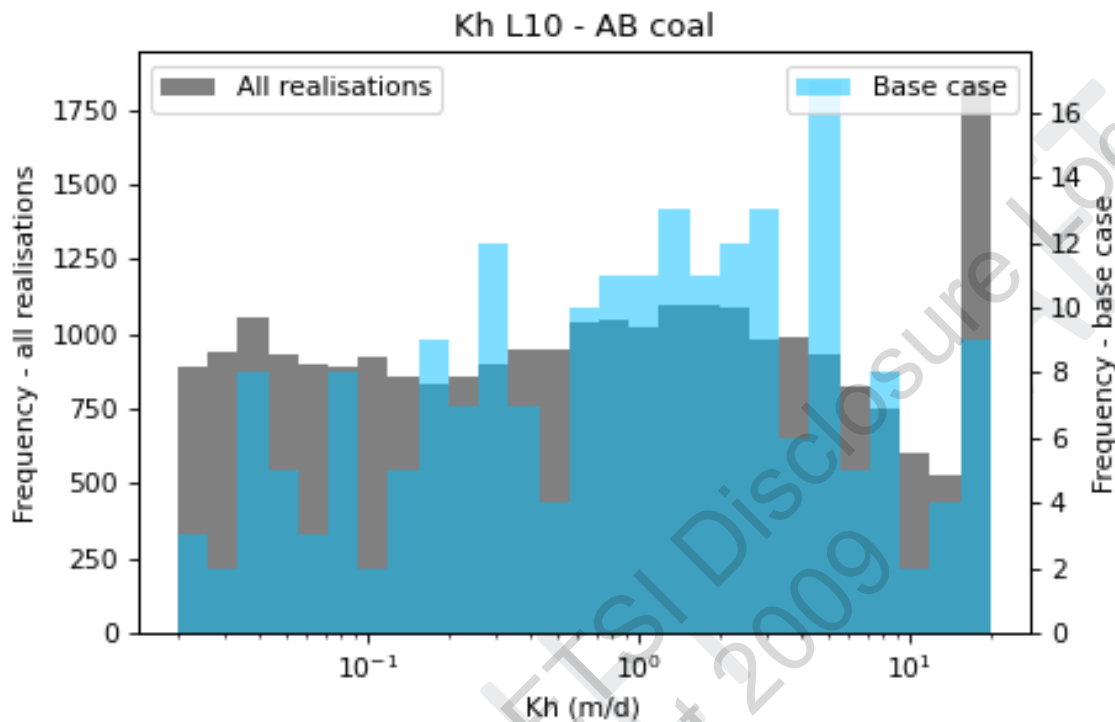


Figure 4.8 Horizontal hydraulic conductivity pilot point parameter frequency distribution for AB Coal across base realisation and uncertainty ensemble

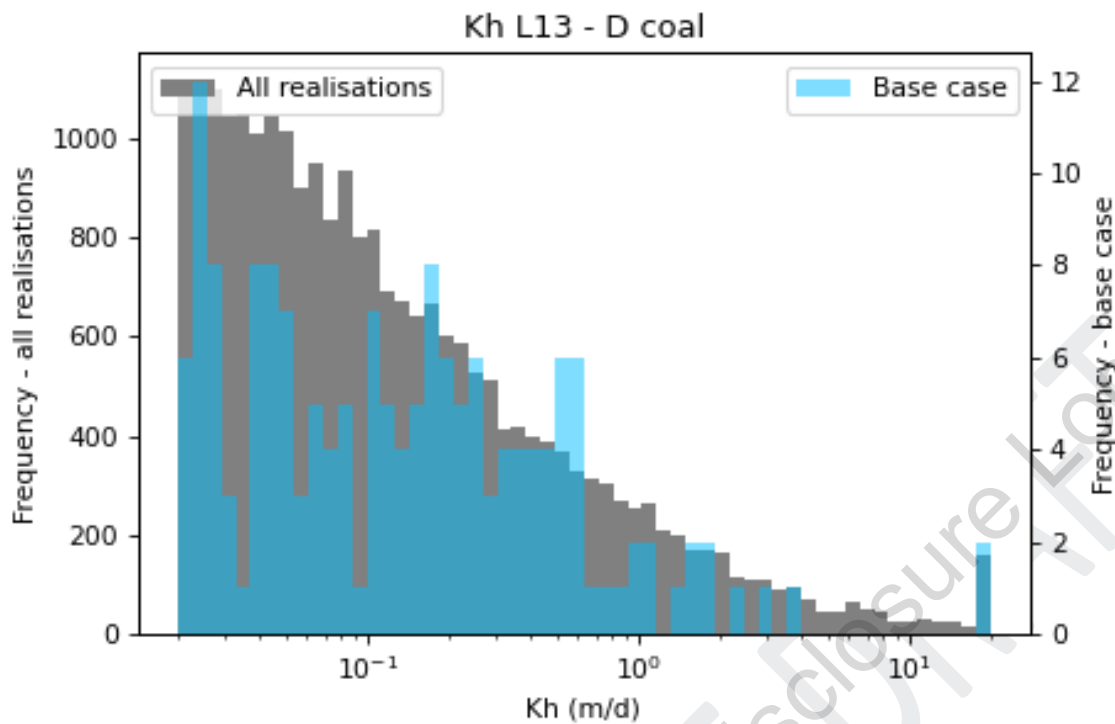


Figure 4.9 Horizontal hydraulic conductivity pilot point parameter frequency distribution for D Coal across base realisation and uncertainty ensemble

The spatial distribution of modelled horizontal hydraulic conductivity in the AB and D coal seams is presented in Figure 4.10 and Figure 4.11 respectively. Unlike shallower layers, lower hydraulic conductivity is simulated north of the Carmichael River for both layers.

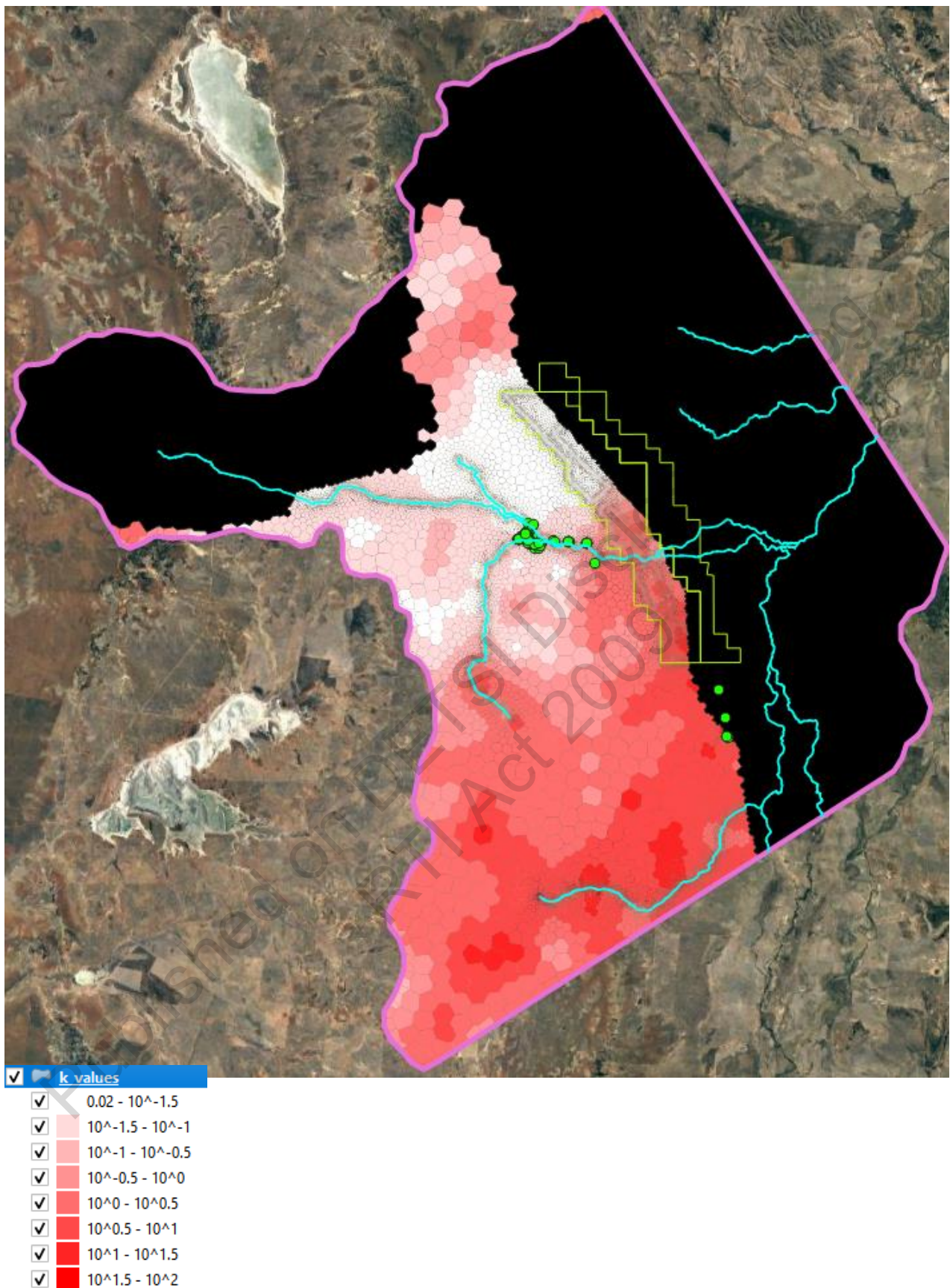


Figure 4.10 Base realisation modelled horizontal hydraulic conductivity in AB Coal seam

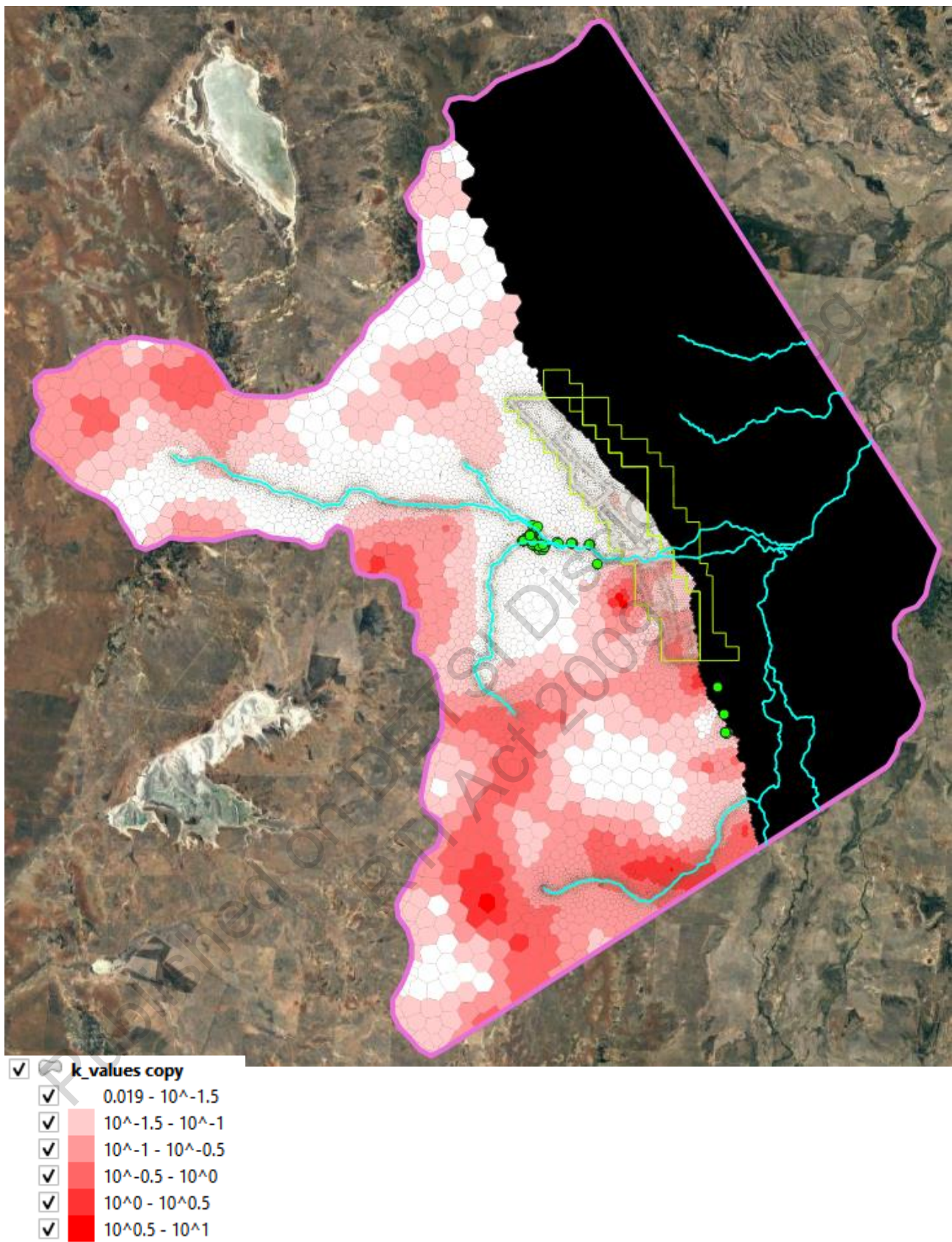


Figure 4.11 Base realisation modelled horizontal hydraulic conductivity in D Coal seam

Frequency distributions for the full suite of modifiable parameters are presented in Appendix B.

4.2 Performance

4.2.1 Statistical performance

History-match performance was statistically quantified using SRMS error for hydraulic head and drawdown, given as a percentage:

$$SRMS = \frac{100}{\Delta H} \sqrt{\frac{1}{n} \sum_{i=1}^n [W_i(z_{hi} - h_i)]^2}$$

where:

- ΔH is the range of measured hydraulic heads across the model domain;
- n is the number of measurements used in the history-match dataset;
- W_i is the statistical weighting (unitless) applied to measurement i ;
- z_{hi} is the modelled hydraulic head/drawdown at location/time i ; and
- h_i is the measured hydraulic head/drawdown at location/time i .

The SRMS error was calculated for initial head measurements, temporal head-change (drawdown), and transient head. No statistical weightings were applied to measurements. The resultant values are presented in Table 4.1.

Table 4.1 SRMS error summary for adopted basecase

History-matching mode	SRMS
Initial hydraulic head	10.9%
Transient head-change	3.4%
Transient head	6.7%

Of the 500-realisation parameter suite, 493 of the models successfully ran to completion of the history-matching period. Statistical results of the suite are presented in Table 4.2.

Table 4.2 SRMS error summary for parameter ensemble

	Initial hydraulic head	Transient head-change	Transient head
Base realisation	10.9%	3.4%	6.7%
Maximum	14.1%	4.7%	8.9%
90 th percentile	13.0%	3.8%	8.2%
Median	12.1%	3.3%	7.5%
10 th percentile	11.4%	2.9%	7.0%

Table 4.2 SRMS error summary for parameter ensemble

	Initial hydraulic head	Transient head-change	Transient head
Minimum	10.5%	2.5%	6.3%

In order to ensure suitable history-matching performance for the uncertainty ensemble, a screening filter was applied with the following cut-off values:

- initial hydraulic head SRMS: 12.5%;
- transient head-change SRMS: 3.5%; and
- transient head SRMS 8.0%.

Following this filtering, 231 parameter realisations were rejected based on poor performance against measured data.

4.2.2 Hydraulic head

i Scatter plot

A scatter plot of modelled against measured hydraulic head

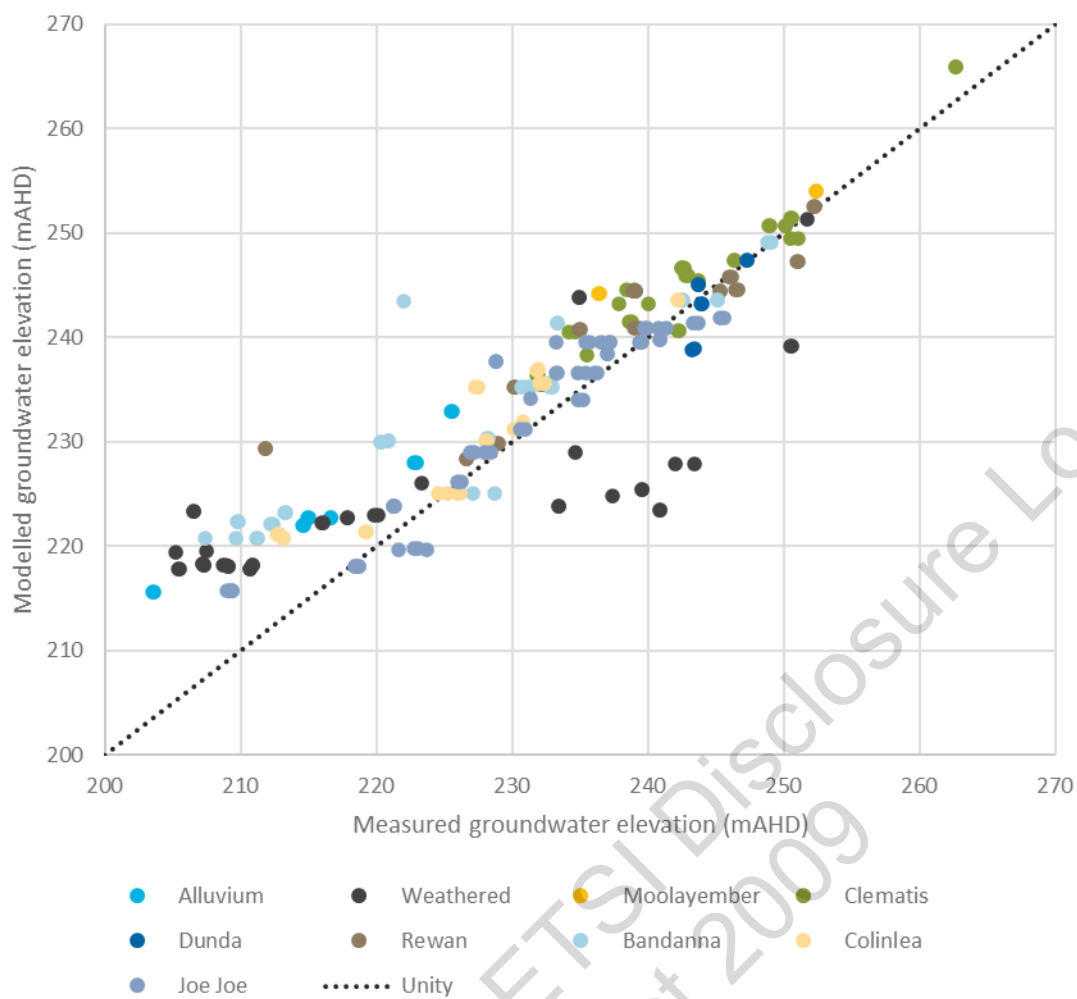


Figure 4.12 Modelled vs measured scatter plot for initial hydraulic head measurements for base realisation grouped by HSU

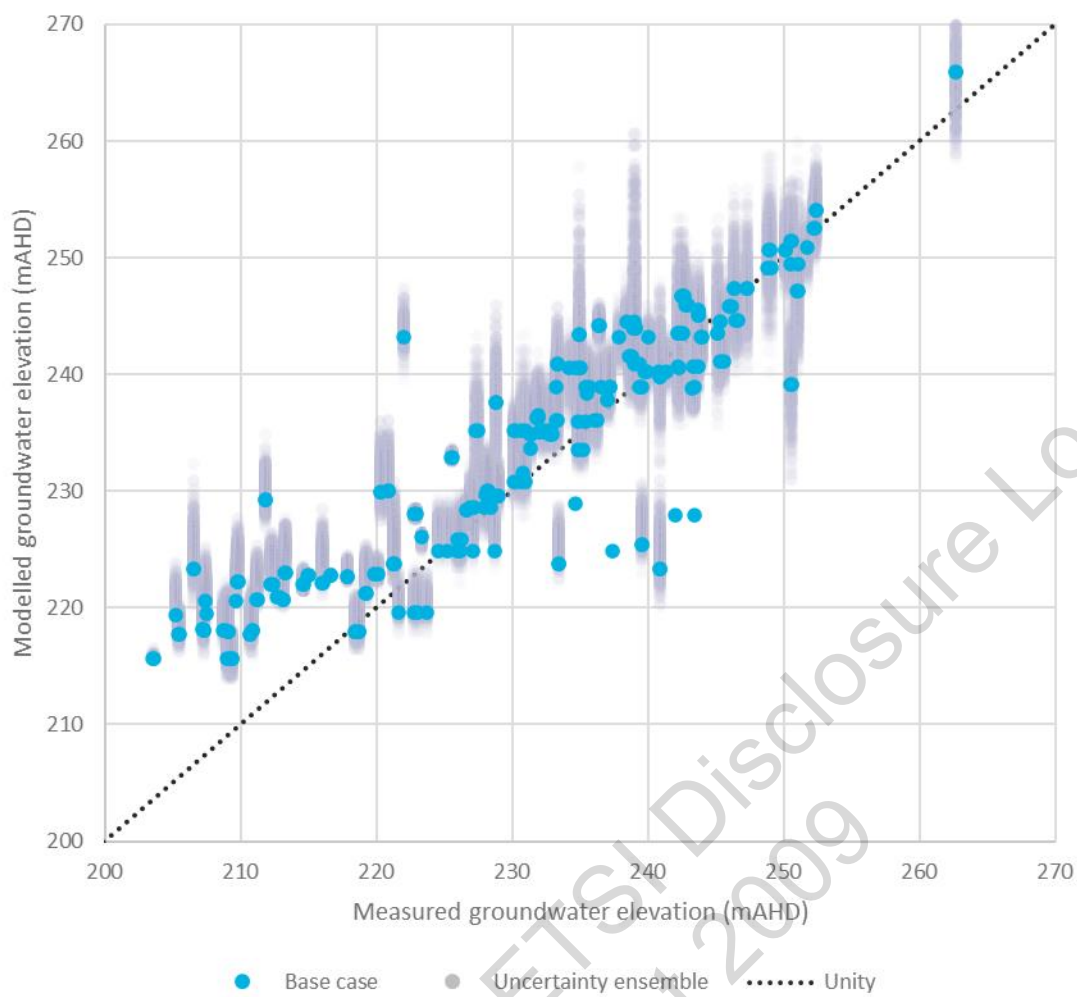


Figure 4.13 Modelled vs measured scatter plot for initial hydraulic head measurements for base realisation and uncertainty suite

ii Modelled groundwater contours

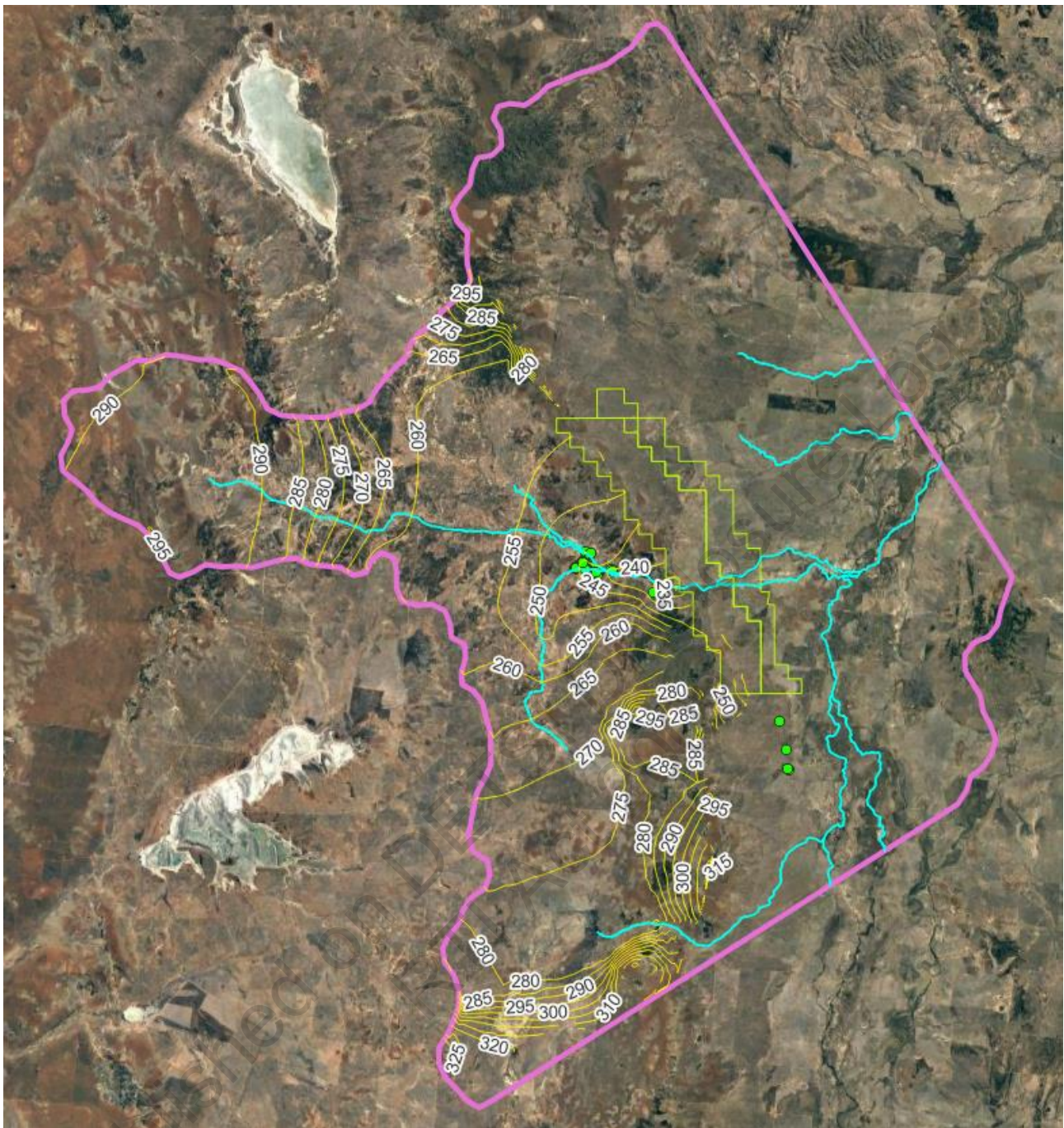


Figure 4.14 Modelled steady-state groundwater level contours in Clematis Sandstone

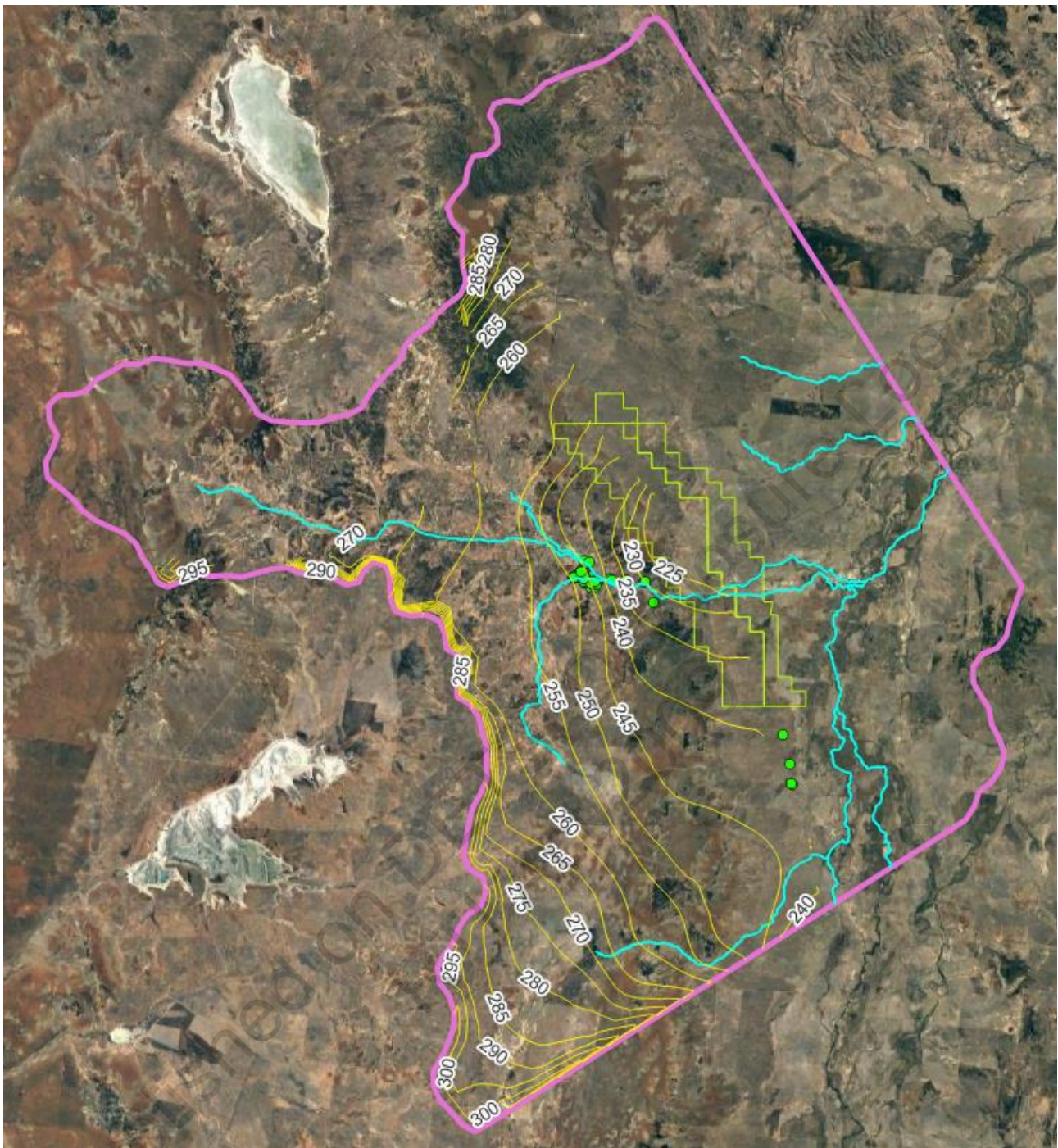


Figure 4.15 Modelled steady-state groundwater level contours in AB Coal

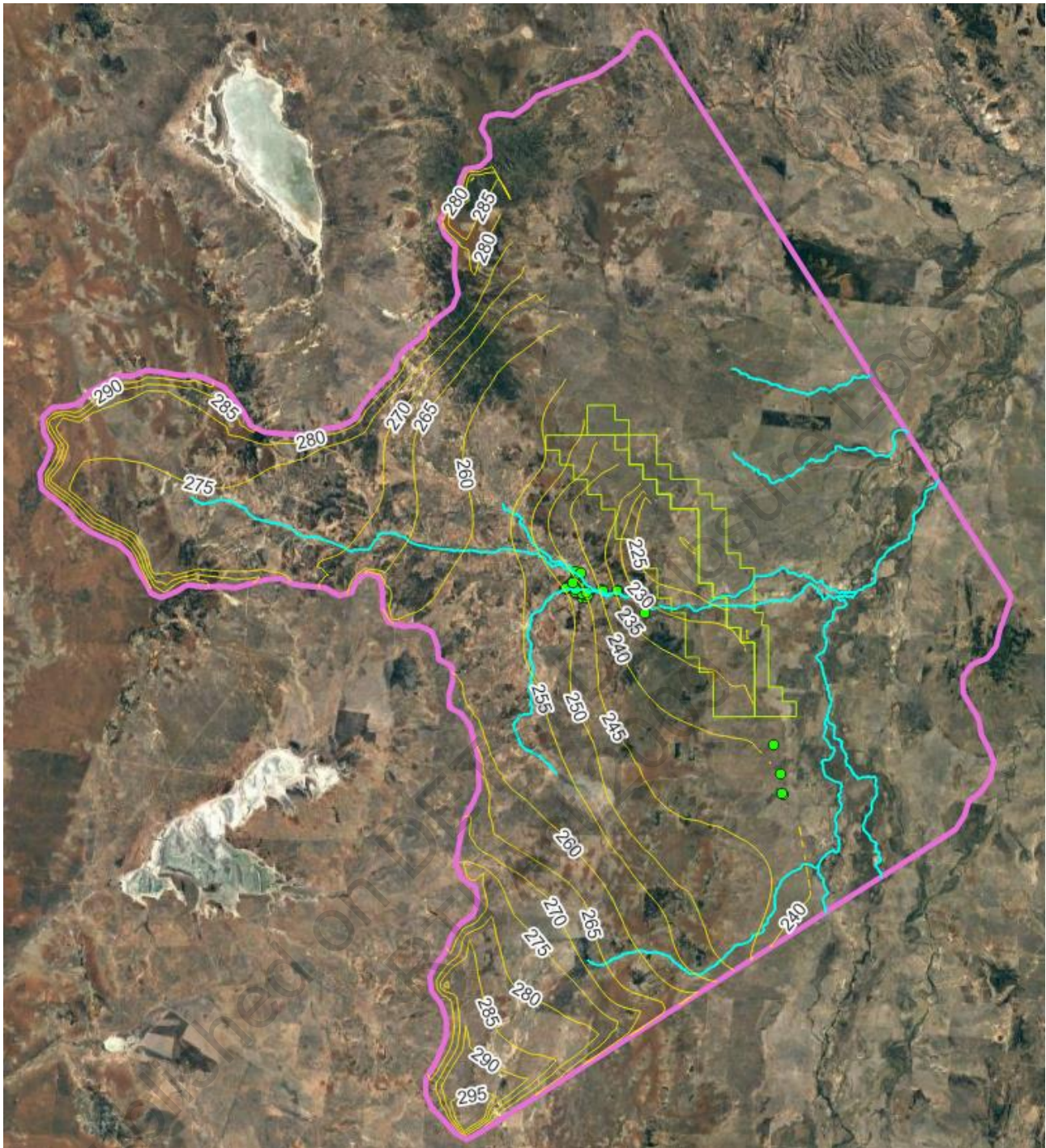


Figure 4.16 Modelled steady-state groundwater level contours in D Coal

iii Modelled hydrographs

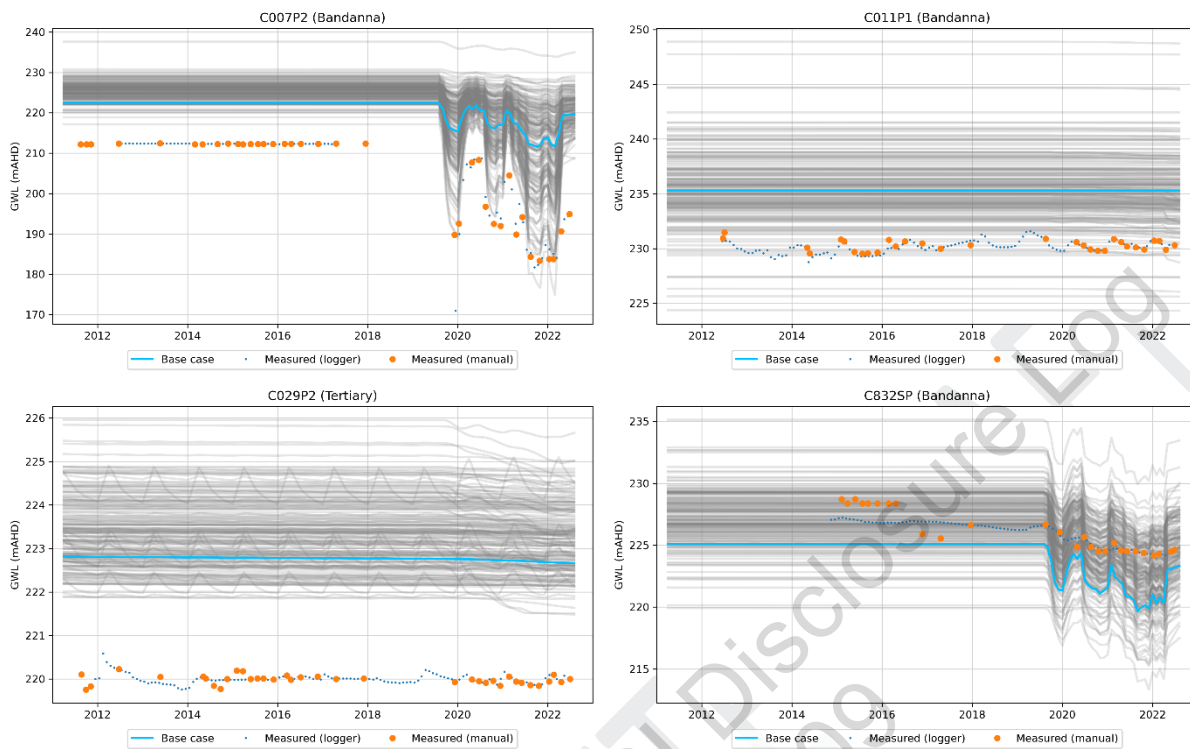


Figure 4.17 Selected history-matching hydrographs

4.2.3 Drawdown

i Scatter plot

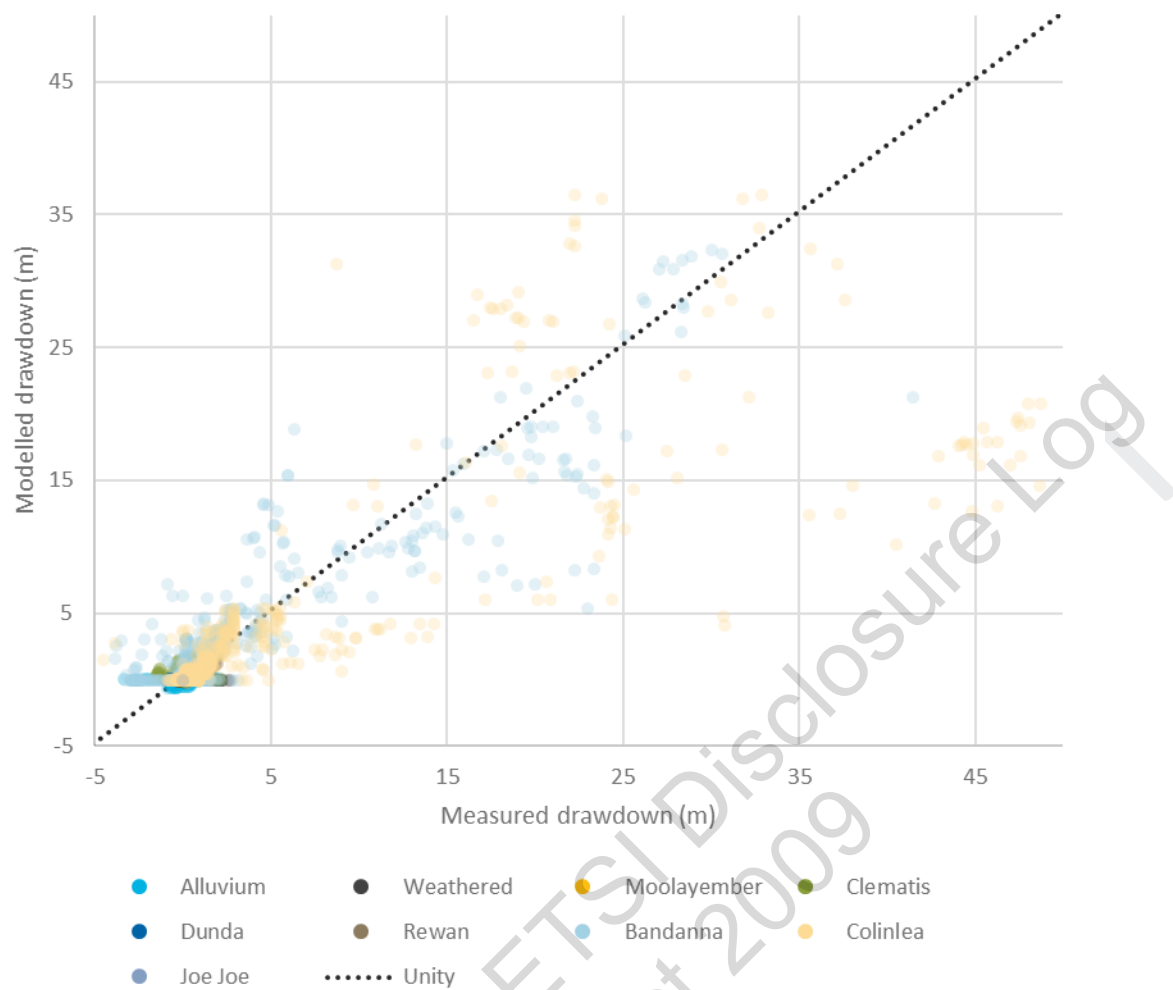


Figure 4.18 Modelled vs measured scatter plot of head-change for base realisation grouped by HSU

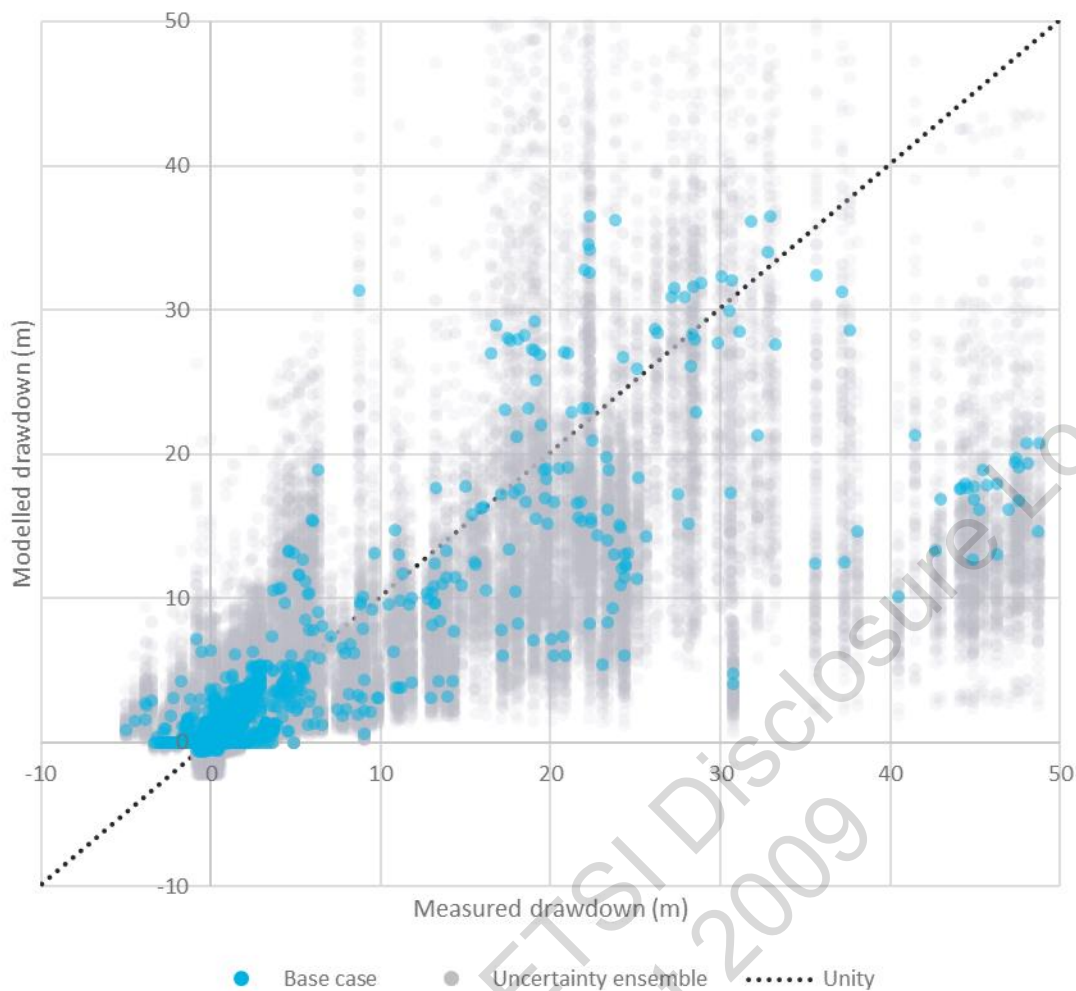


Figure 4.19 Modelled vs measured scatter plot of head change for base realisation and uncertainty suite

4.2.4 Surface water – groundwater interaction

Tom, conceptualisation and then representation of modelled surface water features and how they interact with the groundwater system, was previously severely scrutinised.

Can we produce plots of the following:

- During the wet season (pick maybe the latest?), show spatially where water leaks the most from the creek/river features and recharges the aquifer. Show as a colour flood along features
- During the dry season, are there any areas spatially that show baseflow? Show as a colour flood along features
- Show times series of flow in/out of selected creeks/ivers.



Figure 4.20 Baseflow (gaining) and seepage (losing) regions- wet season



Figure 4.21 Baseflow (gaining) and seepage (losing) regions- dry season

4.2.5 Spring flow

Table 4.3 **Modelled spring flows (kL/d)**

	Joshua Spring	Other Doongmabulla springs
Estimate (EMM 2022b)	1,000	400
Base realisation	912	565
Maximum	1,601	1,470
90 th percentile	1,198	894
Median	802	534
10 th percentile	527	295
Minimum	146	143

4.3 Water balance

Table 4.4 **Modelled steady state water balance**

	Inflow (ML/d)	Outflow (ML/d)
Regional throughflow	33.83	25.60
Rainfall-derived recharge	0.69	-
Evapotranspiration	-	21.72
River baseflow/leakage	14.70	1.89
Spring discharge	1.19	1.17
Storage	-	-
TOTAL	50.40	50.40
IN-OUT		0.00
Mass balance error		0.01%

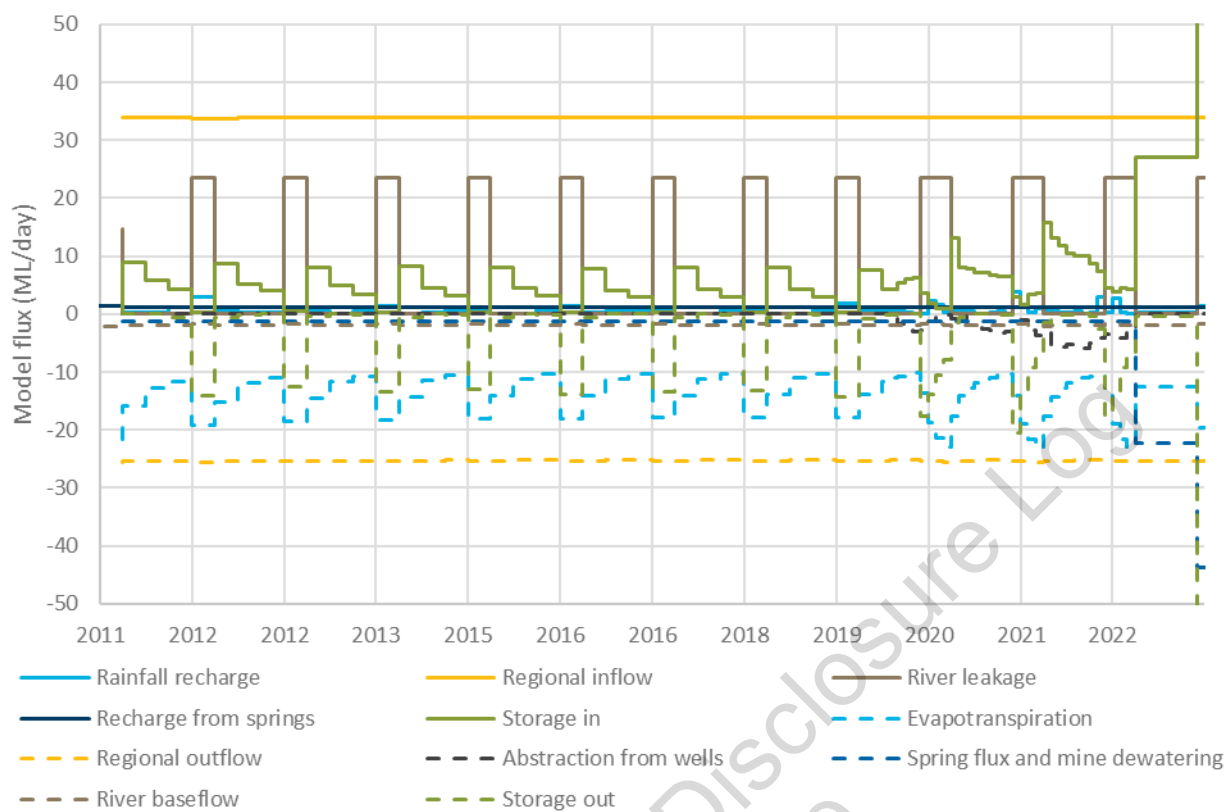


Figure 4.22 Model water balance for the history-matching period

4.4 Comparison with SEIS model

4.4.1 Model parameters

4.4.2 Calibration performance

4.4.3 Clematis heads

4.4.4 Water balance

Table 4.5 Pre- development water balance comparison

2013 SIS balance shown below:

Table 11 Calibrated steady state pre-development model – water balance

Component	SEIS model			Option 1 (2013)
	Flow IN (m ³ /d)	Flow OUT (m ³ /d)	IN – OUT (m ³ /d)	Flow IN (m ³ /d)
Recharge	2,533	0	2,533	2,940
Evapotranspiration	0	4,001	-4,001	0
Discharge from/to Adjoining Areas	44,680	41,466	3,214	84,933
Groundwater Extraction	0	152	-152	0
Carmichael River Leakage	6,662	7,084	-421	6,549
Discharge to Other Water Courses	0	1,200	-1,200	0
TOTAL	53,876	53,904	-28 (-0.05%)	94,422

5 Predictive modelling

5.1 Overview and approach

Three prediction scenarios have been developed including the following:

1. Scenario 1- Open cut only. This scenario includes the simulation of the open cut pits only, with all underground mine workings excluded.
2. Scenario 2- SEIS with previous fracturing assumptions. This scenario uses the updated model but assumes the same fracturing properties (fracturing height and properties multipliers) as the previous GHD 2013 SEIS model. For reference regarding the fracture zone approach, this scenario assumes:
 - a) a 160 m high fracturing height above the mined coal seams.
 - b) an increase in hydraulic conductivity of 2 orders of magnitude for all model cells above mined coal seams to surface.
3. Scenario 3- SEIS with updated fracturing assumptions. This scenario simulated the same mine plan as the SEIS, however the representation of fracturing properties above the longwall have been updated to include the following:
 - a) Fracturing heights were estimated previously as part of the RFCRP, with numerical geomechanical modelling predicting fractures to surface above all longwall panels. In contrast, the Ditton method with a multi-seam correction factor applied, estimated fracturing to a height of 252 m, which covers 48% of the underground mine footprint. For simplicity, this scenario assumed xxx.
 - b) the fractured properties above the longwall panels used the ramp function as outlined in Section **Error! Reference source not found.** below.
 - c) Tom, need to add text related to the increased permeability for the stress relief zone

Scenarios 1, 2 and 3 are compared directly to the 2013 SEIS model, where appropriate, to satisfy Condition E9.

At this stage, an optimised scenario, which will include a modified underground mine plan, has not been developed. The resulting effects on the groundwater system associated with the modified scenario will fall between the results presented for Scenario 1 and Scenario 3, the latter can be considered the 'bookends' of likely groundwater impacts. Therefore, the project at this stage is proposing to assess Scenario 1 as the planned operating scenario, with a commitment to update the groundwater model and associated optimised underground mine plan, prior to one year before underground mining is planned to commence, which is currently at 2037.

5.1.1 Assessing likelihood of drawdown

The maximum drawdown predicted for the Clematis Sandstone and the proportion of exceedance of the 0.2 m threshold set at spring locations are shown in Section 5.3.2. At this stage, full uncertainty analysis and thus the likelihood of drawdown assessment has only been completed for the Open cut only scenario (Scenario 1). The basecase realisations for Scenario 2 and 3 have been developed to allow a comparison to the previous SEIS model (GHD 2013).

The method follows that at each model cell, the drawdown was ranked in terms of magnitude and then the P10, P33, P66, and P90 values were calculated. Each percentile value was then interpolated using an inverse distance weighted algorithm to produce a percentile-based surface (eg one surface for each percentile threshold). A 0.2 m contour were then generated from each percentile surface to allow each of the maps to be amalgamated. This

approach is realisation independent and presents a conservative model cell-based approach to determine the maximum extents for drawdown for each likelihood threshold.

The rationale for the percentile approach to presenting predicted 500 drawdown realisations is based on Table 2 of Middlemis and Peeters (2018). Those uncertainty guidelines describe the importance of calibrated language and having a consistent and precise language to communicate impacts to decision makers.

Table 5.1 provides a summary of the combined numeric, narrative and visual approach to describe likelihood of drawdown exceeding the 0.2 m threshold, as a result of the Project. This table will provide the clarity on how to consider the likelihood bands presented in Figure 5.8 for Scenario 1.

Table 5.1 Combined numeric, narrative, and visual approach for assessing the likelihood of drawdown

Percentile band (outcomes ranked from small to large)	Colour code	
<P10		It is very unlikely that drawdown exceeds the threshold
P10 to P33		It is unlikely that drawdown exceeds the threshold
P33 to P67		It is as likely as not the drawdown exceeds the threshold
P67 to P90		It is likely that drawdown exceeds the threshold
>P90		It is very likely that drawdown exceeds the threshold

5.2 Water balance results

5.2.1 Operational phase

a Overall modelled water balance

Add text here . SEIS model did not document operational water balance.

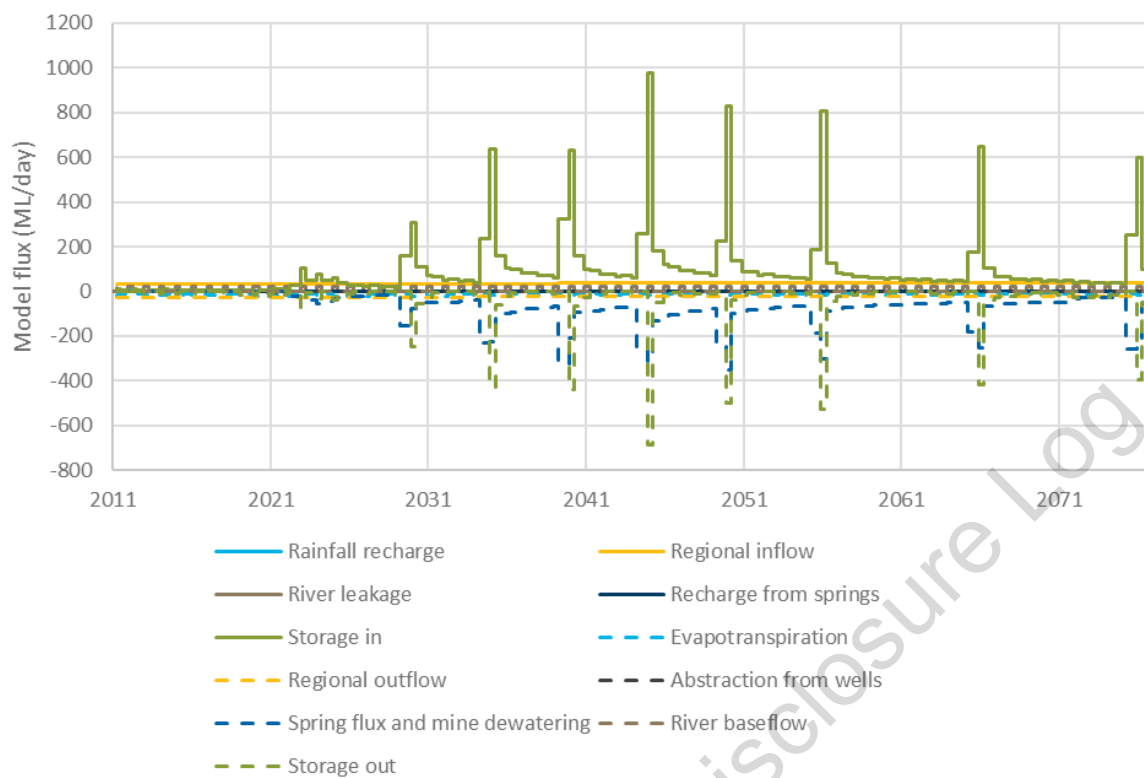


Figure 5.1 Scenario 1 modelled water balance

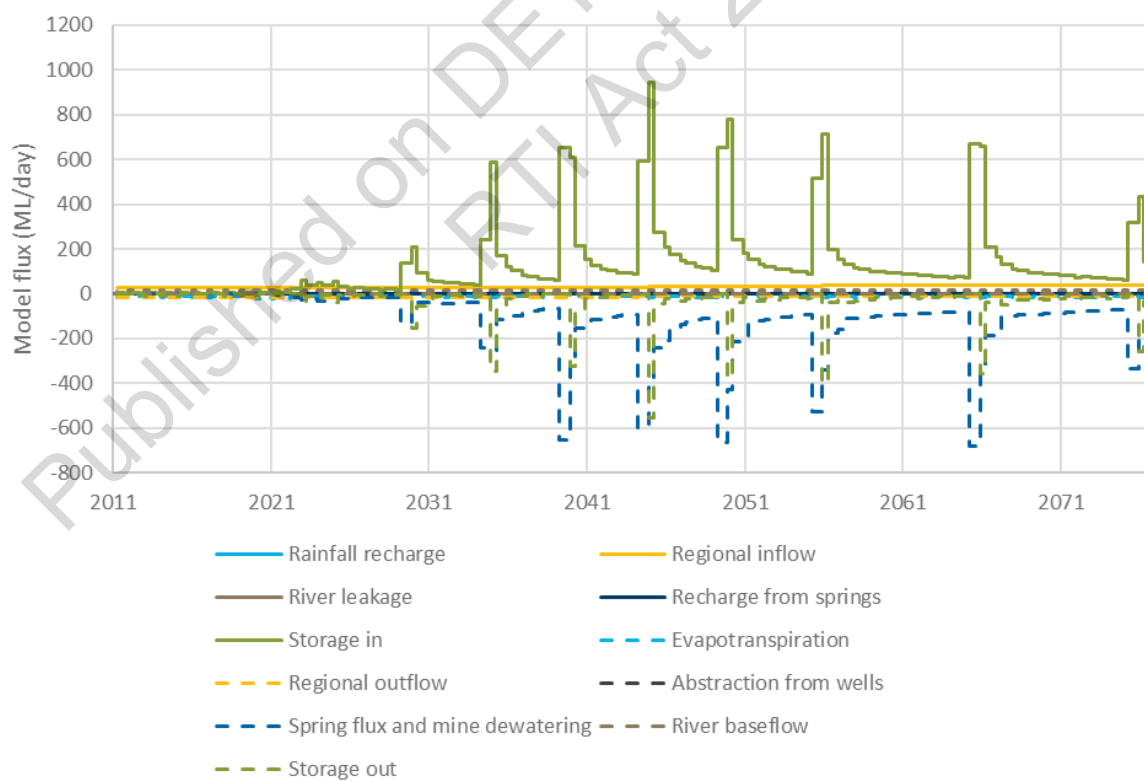


Figure 5.2 Scenario 2 modelled water balance

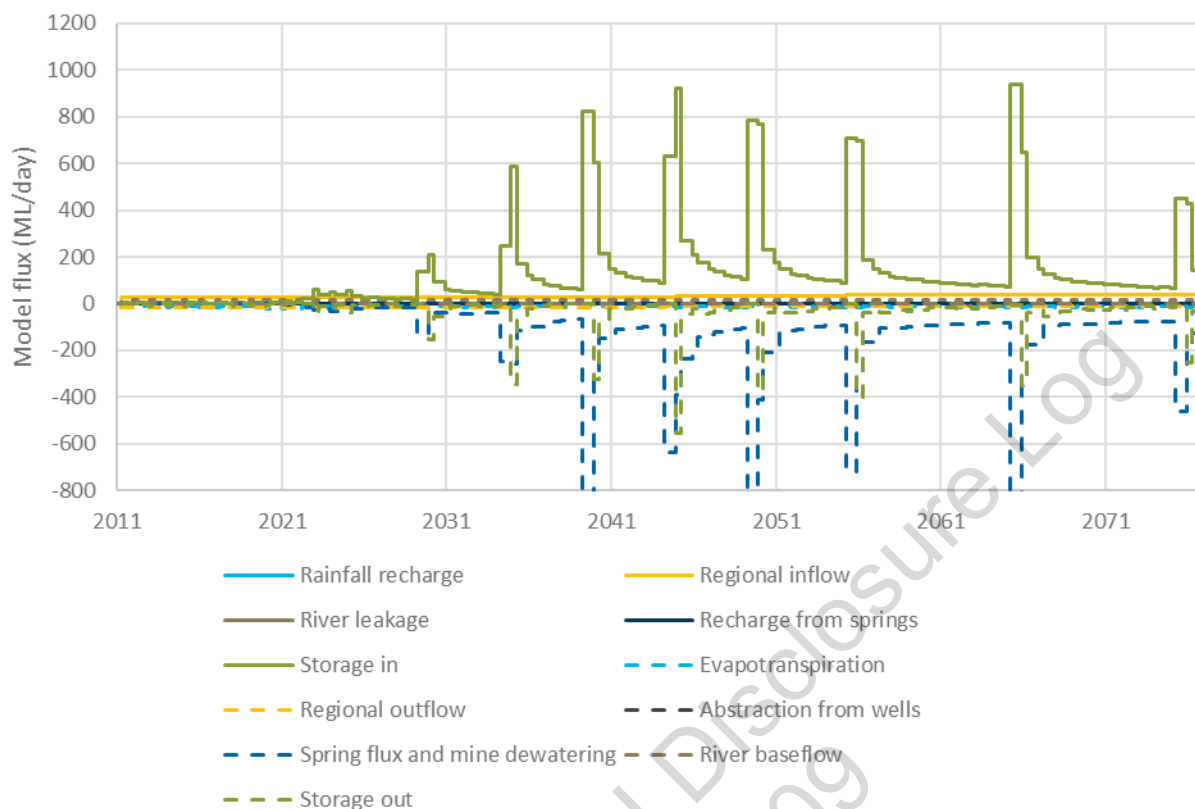


Figure 5.3 Scenario 3 modelled water balance

b Mine inflows

Add figure and text comparison to SEIS

Table 5.2 Prediction mine ingress (ML/day) for Scenario 1

Mine Year	Open cut	Underground	Total
1	0.4	0	0.4
2	0.8	0	0.8
3	3.1	0	3.1
4	29.4	0	29.4
5	43.3	0	43.3
10	63.2	0	63.2
15	113.6	0	113.6
20	121.6	0	121.6
25	134.3	0	134.3
30	108.6	0	108.6
35	78.5	0	78.5

Table 5.2 Prediction mine ingress (ML/day) for Scenario 1

Mine Year	Open cut	Underground	Total
47	60.2	0	60.2

Table 5.3 Prediction mine ingress (ML/day) for Scenario 2

Mine Year	Open cut	Underground	Total
1			0.4
2			0.7
3			2.9
4			20.5
5			26.2
10			53.5
15			118.6
20			198.4
25			226.3
30			203.8
35			136.7
47			141.4

Table 5.4 Prediction mine ingress (ML/day) for the Scenario 3

Mine Year	Open cut	Underground	Total
1			0.4
2			0.7
3			2.9
4			20.5
5			26.2
10			53.5
15			119.2
20			220.4
25			227.8
30			213.1
35			147.8

Table 5.4 Prediction mine ingress (ML/day) for the Scenario 3

Mine Year	Open cut	Underground	Total
47			156.2

Table 5.5 Prediction mine ingress (ML/day) for the 2013 SEIS model (GMMP, 2020)

Mine Year	Open cut	Underground	Total
1	4.9	0	4.9
2	7	0	7
3	11.6	0	11.6
4	10.7	0.1	10.8
5	11.7	1	12.7
10	11.2	5.3	16.5
15	10.6	15.5	26.1
20	8.5	5.8	14.3
25	7.8	7.5	15.3
30	7.8	4.6	12.4
35	7	6.4	13.4
47	6.6	0	6.6

5.2.2 Post closure phase

Compare water balance tables only

Table 5.6 Modelled water balance post closure- Scenario 1

	Inflow (ML/d)	Outflow (ML/d)
Regional throughflow	37.06	23.18
Rainfall-derived recharge	252.81	-
Evapotranspiration	-	195.23
River baseflow/leakage	14.70	1.89
Spring discharge	1.17	1.18
Storage	0.43	0.01
TOTAL	306.17	221.48
IN-OUT		84.69
Mass balance error		27.66%

Table 5.7 **Modelled water balance post closure- Scenario 2**

	Inflow (ML/d)	Outflow (ML/d)
Regional throughflow	29.79	13.44
Rainfall-derived recharge	252.70	-
Evapotranspiration	-	222.02
River baseflow/leakage	11.84	1.40
Spring discharge	0.78	0.79
Storage	0.01	0.03
TOTAL	295.13	237.64
IN-OUT		57.46
Mass balance error		19.47%

Table 5.8 **Modelled water balance post closure- Scenario 3**

	Inflow (ML/d)	Outflow (ML/d)
Regional throughflow	26.99	14.45
Rainfall-derived recharge	252.67	-
Evapotranspiration	-	261.11
River baseflow/leakage	11.84	1.39
Spring discharge	0.77	0.78
Storage	0.16	2.36
TOTAL	292.44	280.08
IN-OUT		12.35
Mass balance error		4.22%

Table 5.9 **Modelled water balance post closure- 2013 SEIS model**

	Inflow (ML/d)	Outflow (ML/d)
Regional throughflow	44.83	41.3
Rainfall-derived recharge	2.53	-
Evapotranspiration	-	3.34
River baseflow/leakage	6.43	6.43

Table 5.9 **Modelled water balance post closure- 2013 SEIS model**

	Inflow (ML/d)	Outflow (ML/d)
Spring discharge	-	0.65
Pumping wells	-	0.15
Flux to pit	-	2.40
Storage	0	0
TOTAL	53.79	54.29
IN-OUT		-0.49
Mass balance error		0.91%

5.3 Drawdown related effects

5.3.1 Overview

xx

5.3.2 Spatial groundwater responses

i Clematis Sandstone

Basecase drawdown and probability of exceedance (Scenario 1 only).

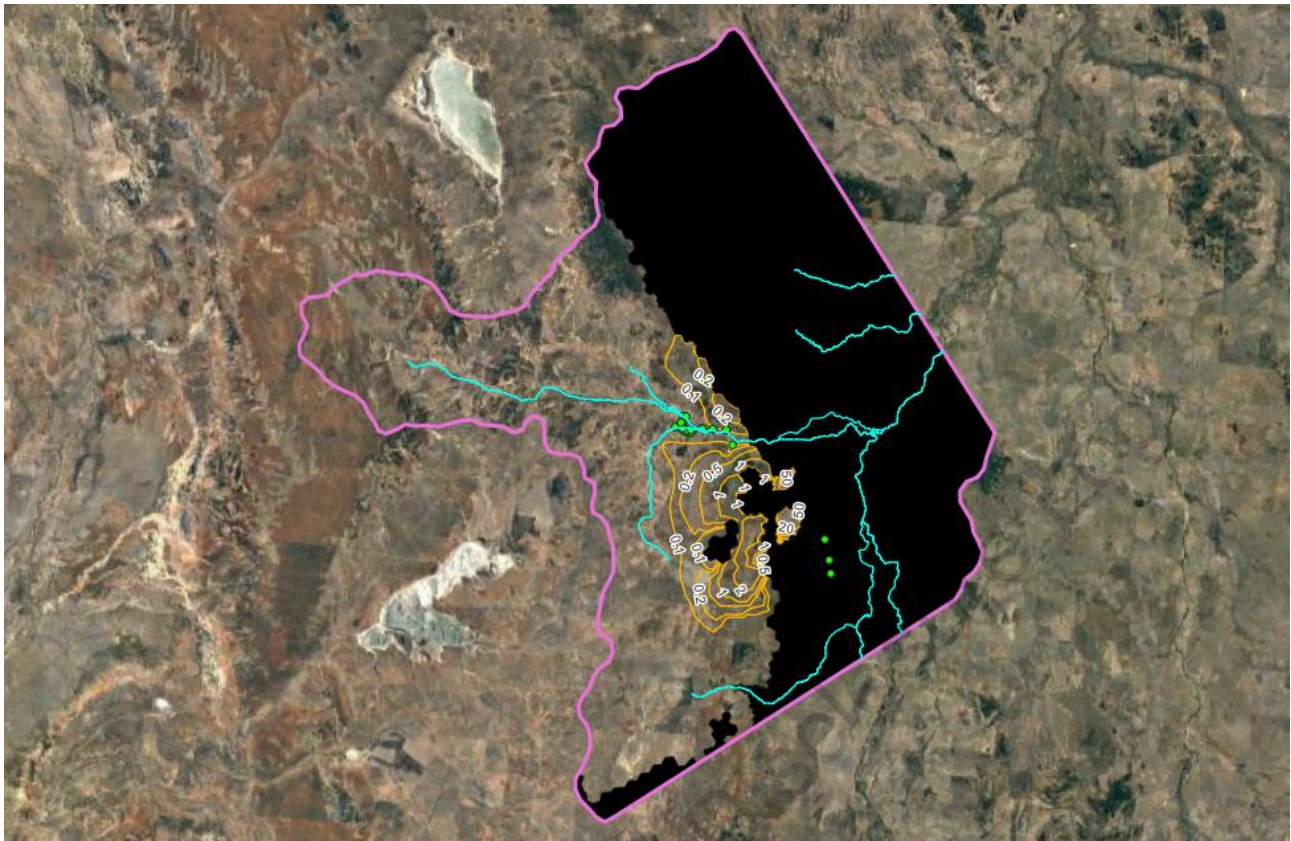


Figure 5.4 Scenario 1 modelled maximum drawdown in Clematis Sandstone

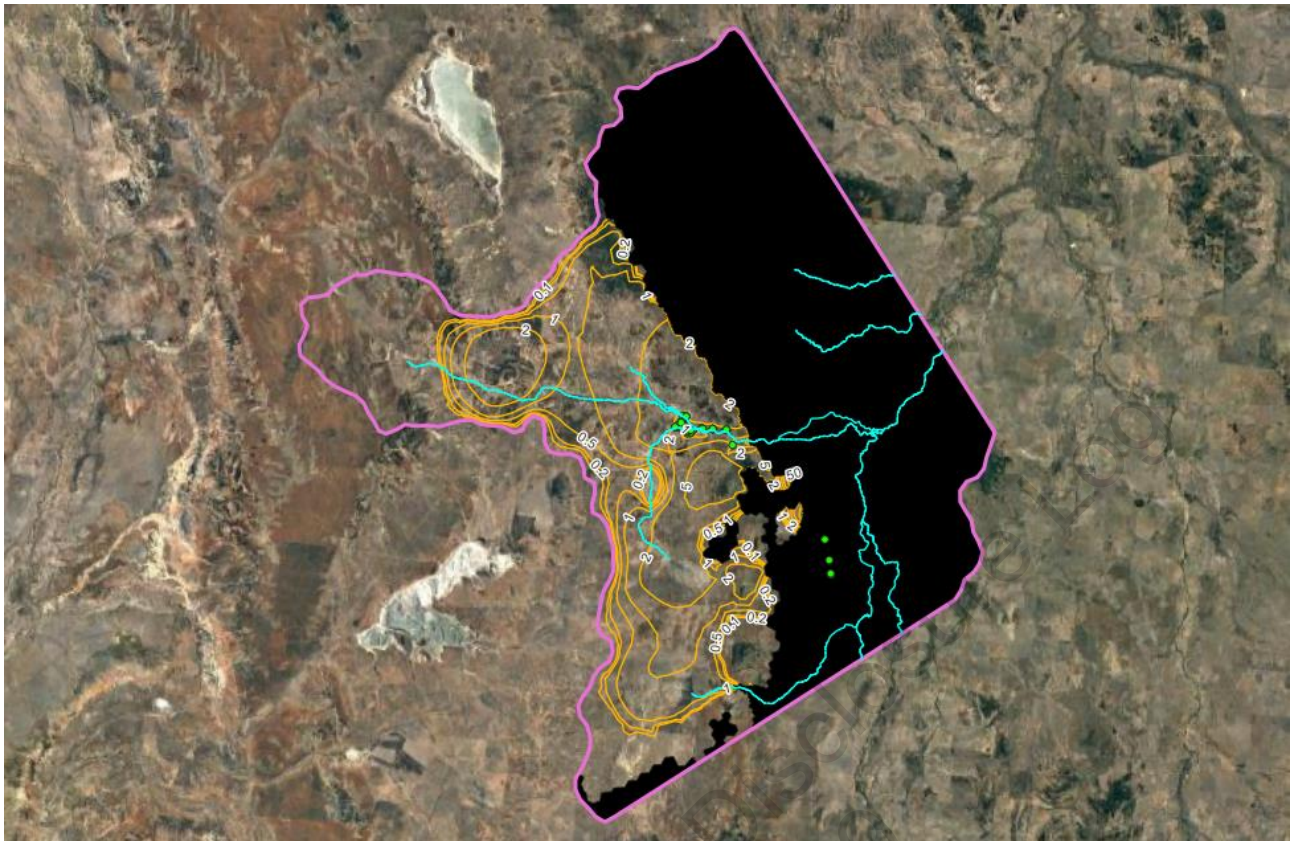


Figure 5.5 Scenario 2 modelled maximum drawdown in Clematis Sandstone

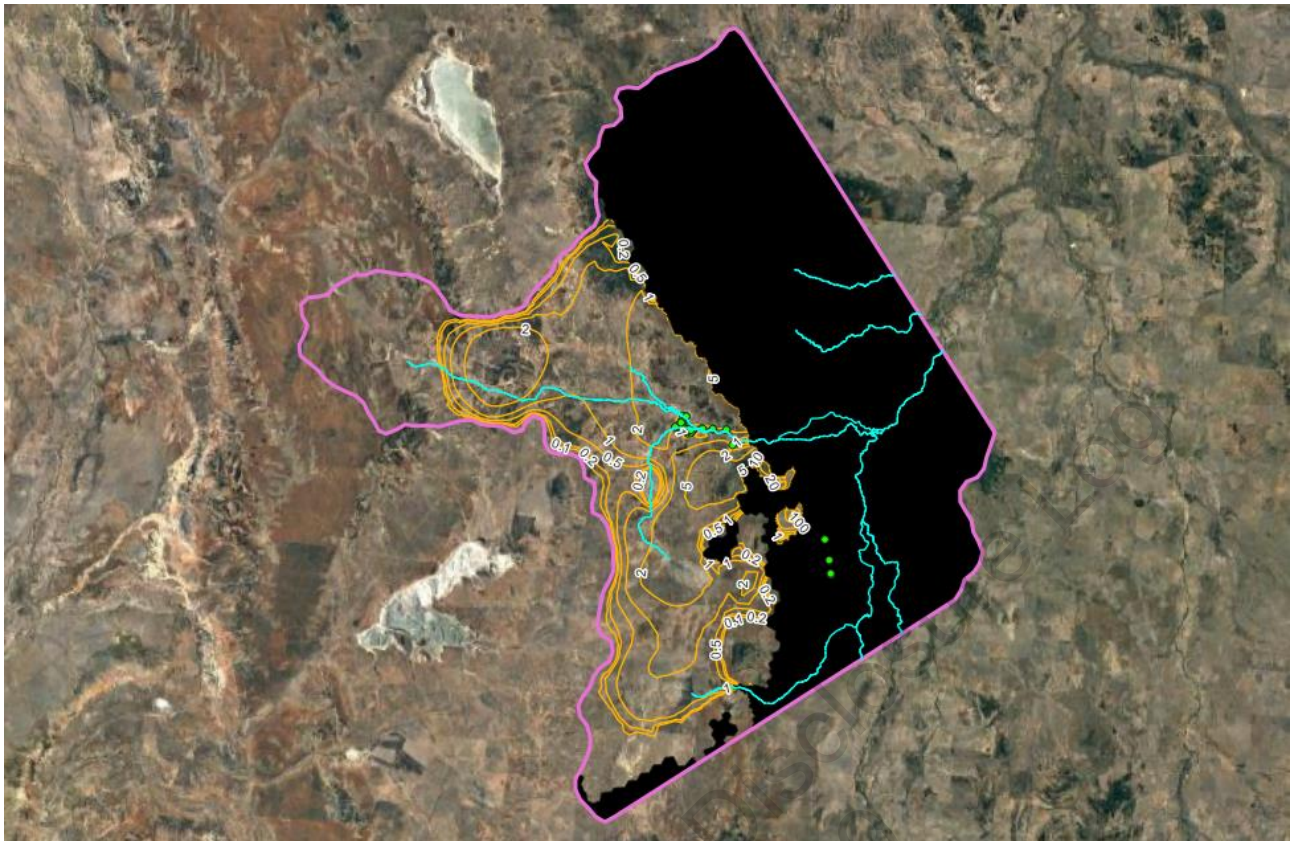


Figure 5.6 Scenario 3 modelled maximum drawdown in Clematis Sandstone

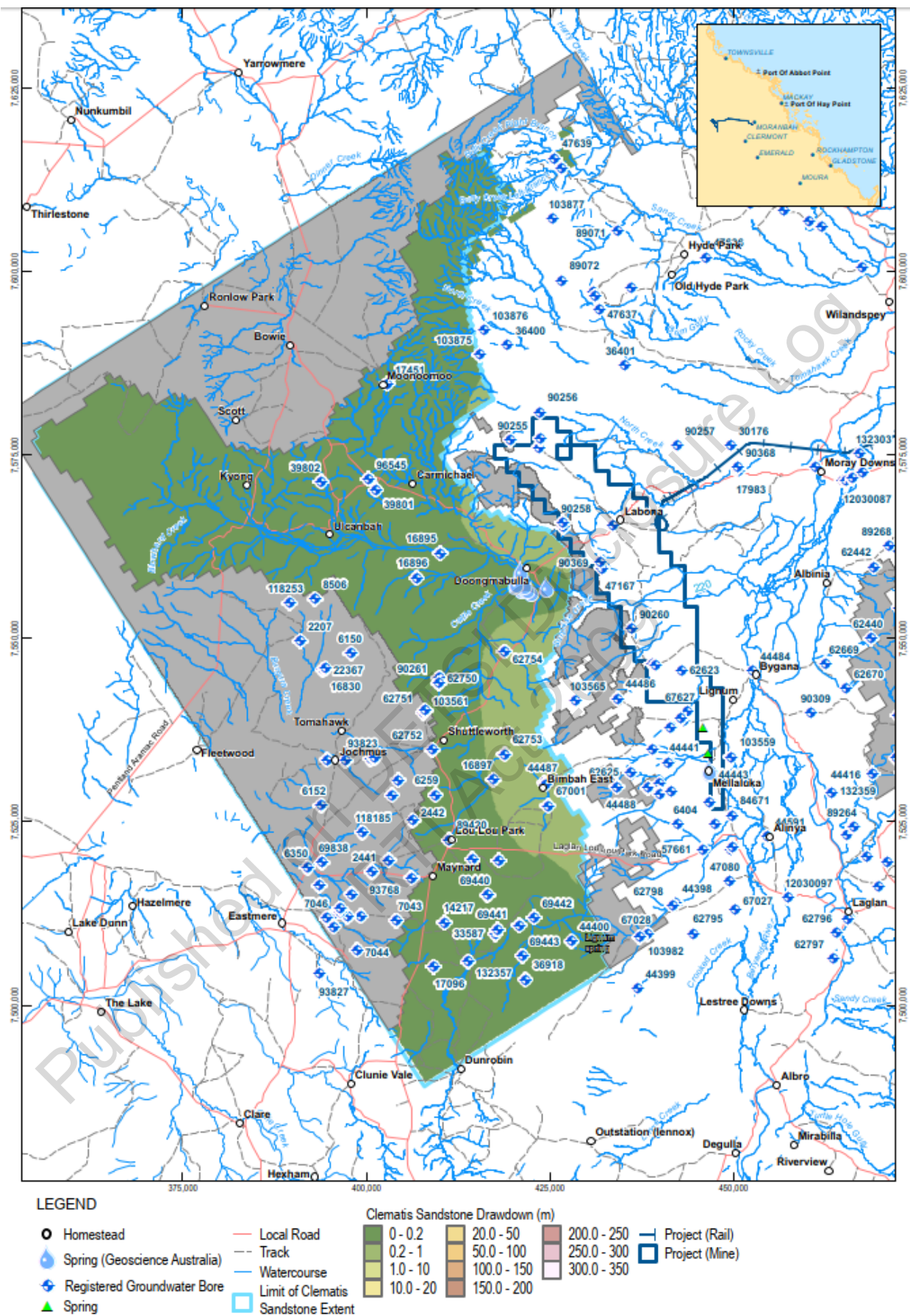
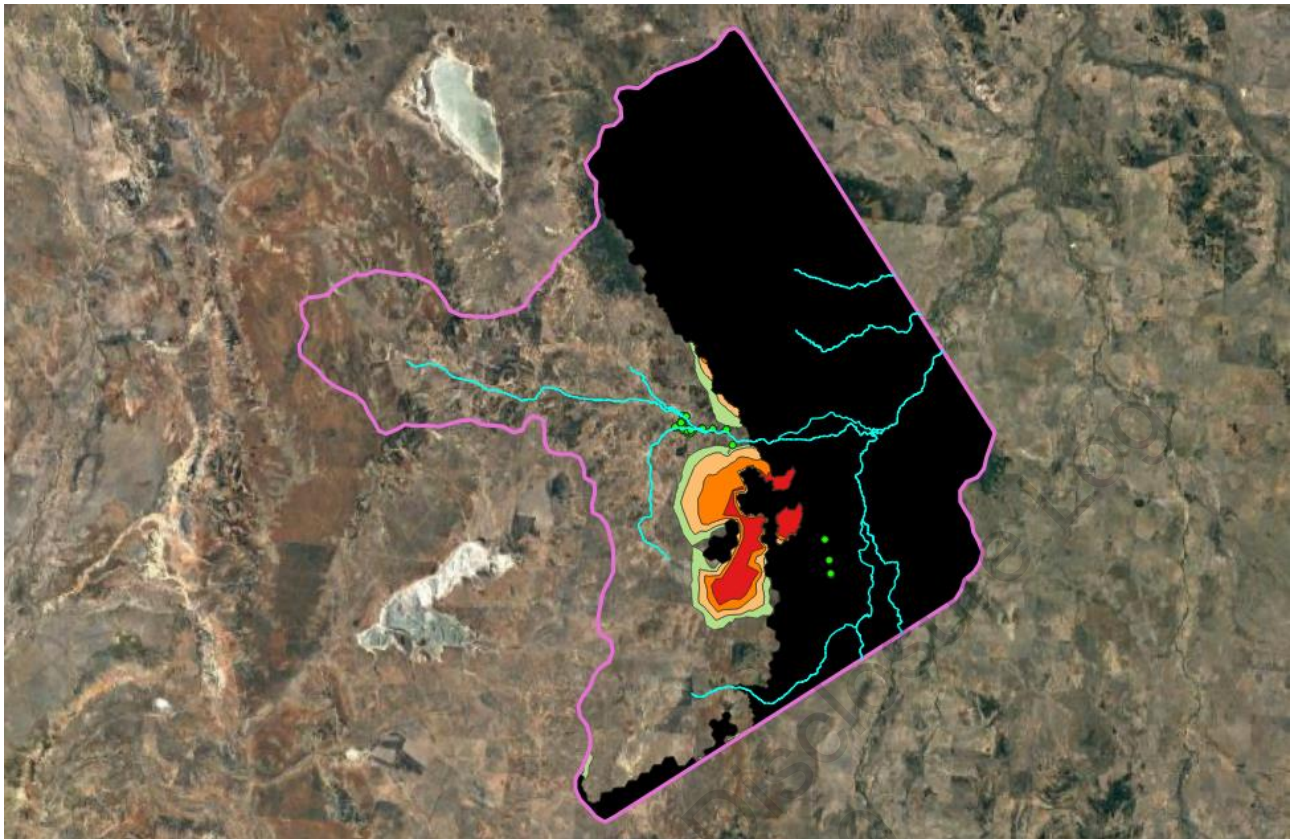


Figure 5.7 2013 SEIS modelled 'long term post closure' drawdown in Clematis Sandstone



Percentile band (outcomes ranked from small to large)	Colour Code	Description of likelihood
<P10	Dark Green	It is very unlikely that the drawdown/mounding exceeds the threshold
P10 to P33	Light Green	It is unlikely the drawdown/mounding exceeds the threshold
P33 to P67	Yellow	It is as likely as not the drawdown/mounding exceeds the threshold
P67 to P90	Orange	It is likely the drawdown/mounding exceeds the threshold
>P90	Red	It is very likely the drawdown/mounding exceeds the threshold

Figure 5.8 Scenario 1 proportion of exceedance for 0.2 m drawdown in Clematis Sandstone

Add text

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RTI Act 2009

Add updated figure

Figure 5.9 Scenario 1 modelled maximum drawdown in AB coal seams

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RTI Act 2009

Add updated figure

Figure 5.10 Scenario 2 modelled maximum drawdown in AB coal seams

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RTI Act 2009

Add updated figure

Figure 5.11 Scenario 3 modelled maximum drawdown in AB coal seams

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RTI Act 2009

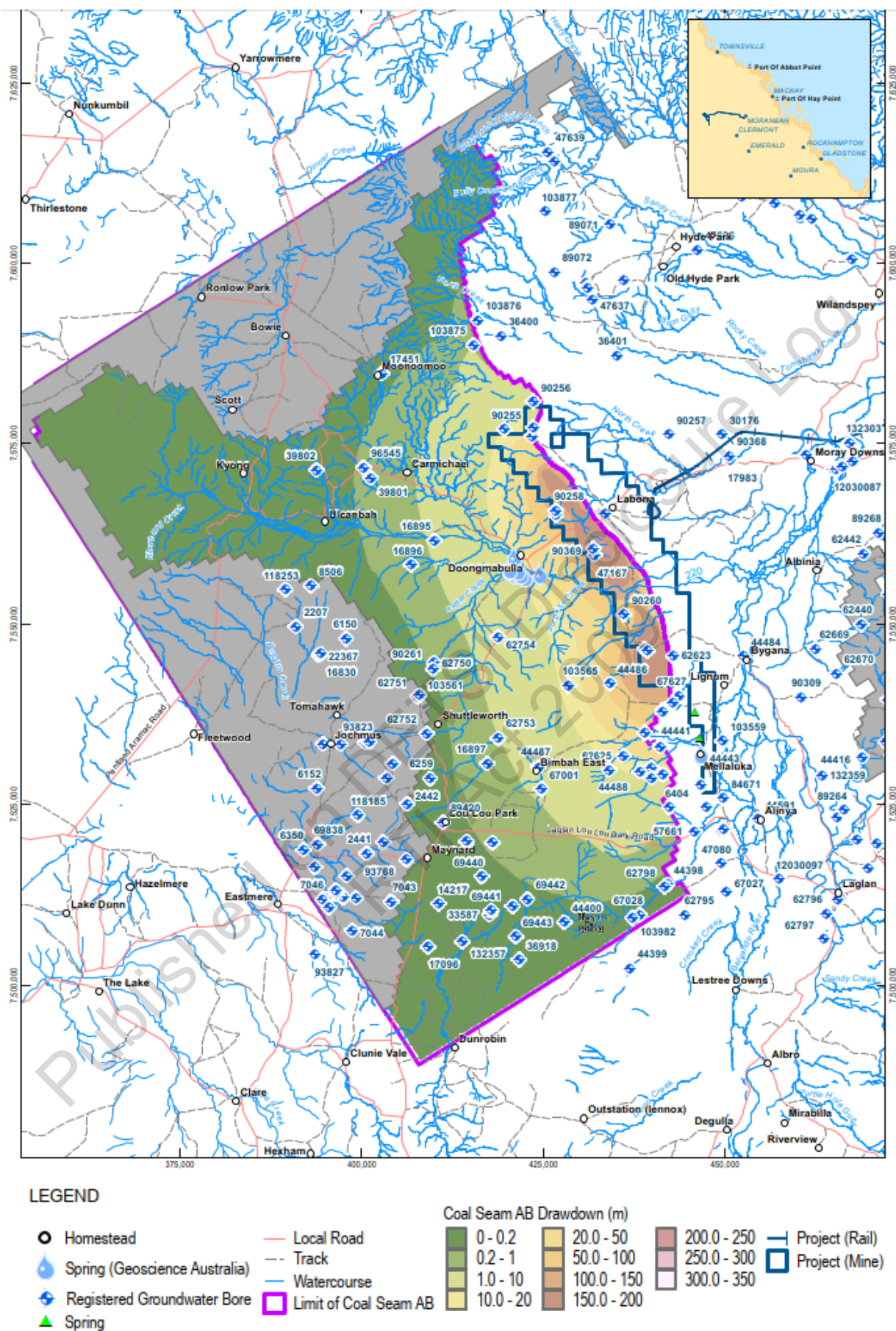


Figure 5.12 2013 SEIS modelled 'long term post closure' drawdown in AB coal seams

5.3.3 Drawdown hydrographs

Figure 5.13 All scenario base case selected modelled drawdown hydrographs

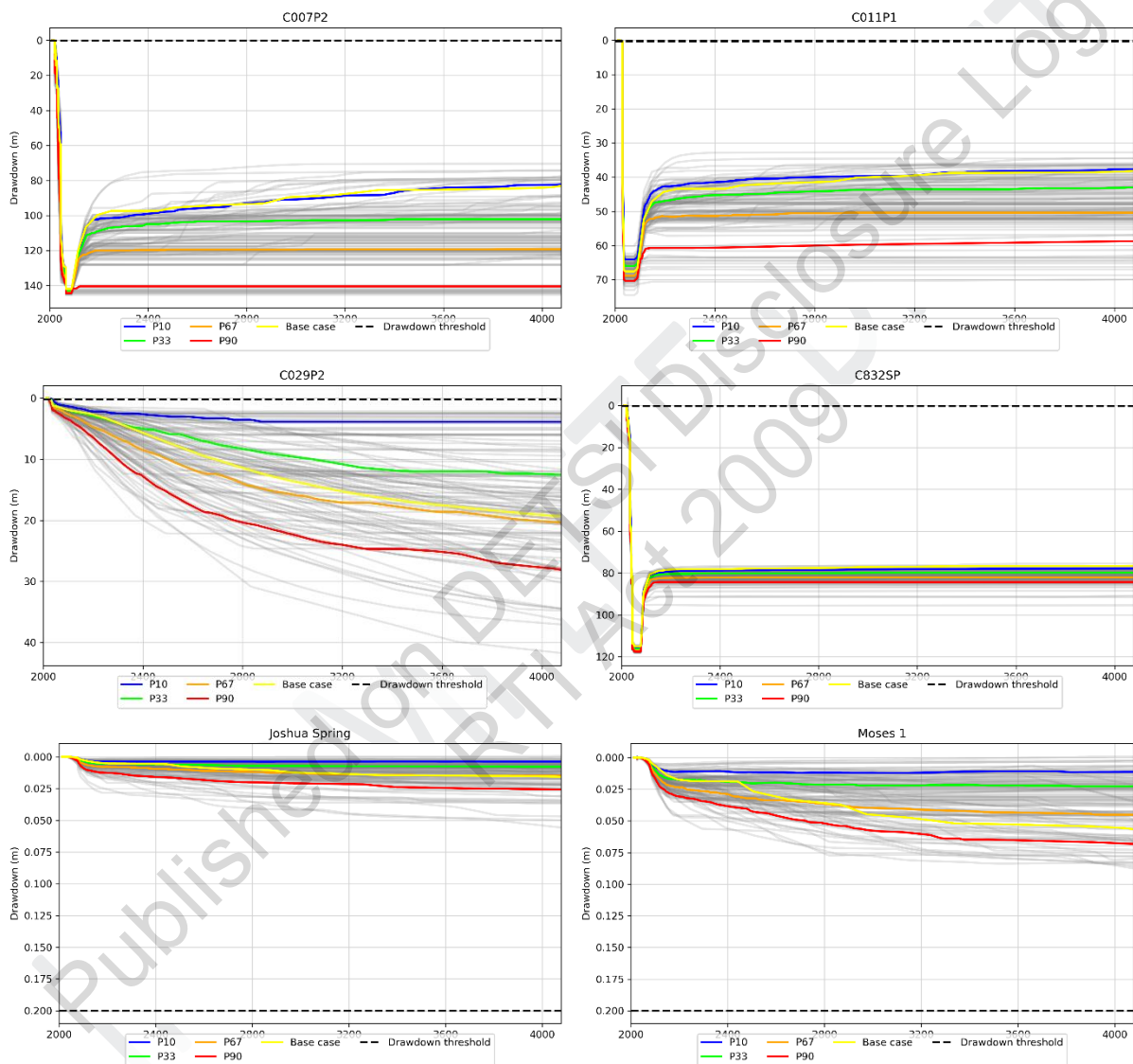


Figure 5.14 Scenario 1 selected modelled drawdown hydrographs



Figure 5.15 Scenario 2 selected modelled drawdown hydrographs

Figure 5.16 Scenario 3 selected modelled drawdown hydrographs

5.3.4 Drawdown at springs

Table 5.10 Modelled maximum drawdown at springs for the base scenarios (m)

Spring ID	Alternate ID	GHD (2013a)-operational	GHD (2013a)-post closure	Scenario 1	Scenario 2	Scenario 3
1031_Moses4	Moses 4	<0.05	<0.05	0.05	0.12	0.31

Table 5.10 **Modelled maximum drawdown at springs for the base scenarios (m)**

Spring ID	Alternate ID	GHD (2013a)- operational	GHD (2013a)- post closure	Scenario 1	Scenario 2	Scenario 3
1032_Moses3	Moses 3	<0.05	<0.05	0.05	0.12	0.31
1033_Moses2	Moses 2	0.08	0.08	0.05	0.12	0.31
1034_Littmose	Little Moses 1	<0.05	<0.05	0.05	0.08	0.24
1035_Moses1	Moses 1	0.06	0.06	0.06	0.13	0.32
1036_75E		0.09	0.09	0.05	0.12	0.31
1037_75A		0.08	0.07	0.05	0.12	0.31
1038_75D		0.07	0.07	0.05	0.12	0.31
1039_75B		0.12	0.11	0.06	0.12	0.31
1040_75C		0.12	0.11	0.06	0.12	0.31
1041_Doongma	Joshua Spring	0.19	0.16	0.02	0.03	0.13
41_(no name recorded)	Mellaluka 1	<0.05 – 1.03	1.6 – 8.39	10.90	4.70	6.17
42_(no name recorded)	Mellaluka 2	<0.05 – 1.14	2.9 – 9.07	10.95	4.67	6.20
Storie's	Storys	<0.05 – 2.34	8.2 – 13.4	18.11	12.42	13.25
Lignum	Lignum	0.06 – 8.22	14.8 – 25.6	7.30	7.17	8.66

Also should show drawdown hydrographs at selected springs (maybe 3 locations?) for base cases vs GHD SEIS model

Table 5.11 **Proportion of model realisations exceeding 0.2 m drawdown threshold for “Open cut” only scenario**

Spring ID	Alternate ID	Percentage of exceedance
1031_Moses4	Moses 4	0%
1032_Moses3	Moses 3	0%
1033_Moses2	Moses 2	0%
1034_Littmose	Little Moses 1	0%
1035_Moses1	Moses 1	0%
1036_75E		0%
1037_75A		0%
1038_75D		0%
1039_75B		0%

Table 5.11 **Proportion of model realisations exceeding 0.2 m drawdown threshold for “Open cut” only scenario**

Spring ID	Alternate ID	Percentage of exceedance
1040_75C		0%
1041_Doongma	Joshua Spring	0%

5.3.5 Drawdown at 3rd party bores

Just a table for comparison. Use Craig’s updated bore list.

Table 5.12 Predicted drawdown (m) at 3rd party bores for basecase scenarios

Site ID (RN)	Local bore name	Formation	Easting	Northing	GHD (2013a)- operational	GHD (2013a)- post closure	Scenario 1	Scenario 2	Scenario 3
TBA	Dexter bore	Permian Overburden/ Tertiary	445677	7540047					
103249	Desert Bore	Permian Overburden/ Tertiary	442972	7538727	8.2	85.9			
158471 or 44484 (GHD 2013)	House Bore	Tertiary/Joe -Joe formation	449378	7541377					
N/A	Tapgate bore	Tertiary/Joe -Joe formation	448517	7544827					
N/A	Shed bore	Tertiary/Joe -Joe formation	446876	7547938					
158001	Lake bore	Tertiary/Joe -Joe formation	446122	7549419					
TBA	Hut bore	Tertiary/Joe -Joe formation	449869	7550061					
44486	Desert Bore	Dunda Beds	434344	7542064	3.1	4.7			
TBA	Clayholes bore	Clematis Sandstone	424733	7536432					
44487	Bimbah House Bore	Clematis Sandstone	424155	7529828					
67626	Bimbah Irrigation bore	Clematis Sandstone	424155	7529828	0.2	0.5			

Table 5.12 Predicted drawdown (m) at 3rd party bores for basecase scenarios

Site ID (RN)	Local bore name	Formation	Easting	Northing	GHD (2013a)- operational	GHD (2013a)- post closure	Scenario 1	Scenario 2	Scenario 3
TBA	Glens Bore	Dunda beds/Clematis (TBC)	429833	7532978					
44488	Cockatoo Bore	Dunda beds	432768	7533696					
62625	Soak Bore	Dunda Beds	435979	7534079	1.1	3.7			
132959	Gidgea Bore	Joe-Joe formation	446731	7528369					
103378	Iron Bark Bore	Rewan formation / Dunda beds	441486	7528898					
103230	3 mile bore	Tertiary/Dunda Beds	441722	7532437	0.4	28.6			
103229	Desert Bore	Tertiary	442930	7538681	8.6	75.1			
132961	Middle Bore	Interburden in early permian	442929	7534861					
103231	Poison Bore	Tertiary/Dunda Beds	438212	7535068	4.5	38.8			
103559	Stories bore	Tertiary/ Joe -Joe	446437	7534364	0.8	4.5			
90212	Shellys bore	Rewan formation / Dunda beds	439949	7529980					
44443	House bore	Tertiary/ Joe -Joe	446729	7532074					
103680	Gold Lotto	Tertiary/Sand stone	446002	7556100					
158649	Satr Light	Tertiary/Sand stone	448146	7554149					

Table 5.12 Predicted drawdown (m) at 3rd party bores for basecase scenarios

Site ID (RN)	Local bore name	Formation	Easting	Northing	GHD (2013a)- operational	GHD (2013a)- post closure	Scenario 1	Scenario 2	Scenario 3
17983 (TBC)	Eight Mile Bore	Tertiary (TBC)	451231	7572656					
17981 (TBC)	10 Mile Bore	Tertiary (TBC)	423365	7575902	18.1 (Permian Sandstone, L10)	23.6			
90255 (TBC)	15 Mile bore	Tertiary (TBC)	419310	7577204	0.8 (Clematis/Dunda)	0.8			
TBA	Yambina Bore	Tertiary (TBC)	457184	7571423					
TBA	Crazy Bore	Dunda beds	414230	7576676					
TBA	Wild Bore	Dunda beds	415707	7574934					
103423	Gidgea No.1 Bore	Assumed above Clematis	446731	7528369	n/a (new bore)	n/a (new bore)			
132960	Gidgea No.2 Bore	Clematis (assumed)	446731	7528369	n/a (new bore)	n/a (new bore)			
TBA	Carmichael House Bore	Moolayember or Clematis	406312	7570944	n/a (new bore)	n/a (new bore)			
TBA	Kades Bore	Moolayember or Clematis	406128	7571872	n/a (new bore)	n/a (new bore)			
TBA	Cow Paddock Bore	Moolayember or Dunda	409855	7570961	n/a (new bore)	n/a (new bore)			
96545	Mosquito Bore	Moolayember or Clematis	400432	7571736	n/a (new bore)	n/a (new bore)			
158631	Riverlane Bore	Tertiary	451106	7541406	n/a (new bore)	n/a (new bore)			

5.3.6 Predicted baseflow assessment and comparison to 2013 SEIS model

Only show losing and gaining spatial maps in history match section. Table below should be satisfactory.

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Table 5.13 Predicted baseflow assessment

Component	All river features	Carmichael River
2013 SEIS model		
Baseflow- history match (m ³ /d)	n/a	
Baseflow- end of operation (m ³ /d)	n/a	
Baseflow- long term post closure (m ³ /d)	n/a	
Baseflow rate change (m ³ /d)- end of operation	n/a	
Baseflow percentage change (%)- end of operation	n/a	
Baseflow rate change (m ³ /d)- long term post closure	n/a	
Baseflow percentage change (%)- long term post closure	n/a	
Scenario 1		
Baseflow- history match (m ³ /d)		
Baseflow- end of operation (m ³ /d)		
Baseflow- long term post closure (m ³ /d)		
Baseflow rate change (m ³ /d)- end of operation		
Baseflow percentage change (%)- end of operation		
Baseflow rate change (m ³ /d)- long term post closure		
Baseflow percentage change (%)- long term post closure		
Scenario 2		
Baseflow- history match (m ³ /d)		
Baseflow- end of operation (m ³ /d)		
Baseflow- long term post closure (m ³ /d)		
Baseflow rate change (m ³ /d)- end of operation		
Baseflow percentage change (%)- end of operation		
Baseflow rate change (m ³ /d)- long term post closure		
Baseflow percentage change (%)- long term post closure		
Scenario 3		
Baseflow- history match (m ³ /d)		
Baseflow- end of operation (m ³ /d)		
Baseflow- long term post closure (m ³ /d)		
Baseflow rate change (m ³ /d)- end of operation		
Baseflow percentage change (%)- end of operation		
Baseflow rate change (m ³ /d)- long term post closure		

Table 5.13 Predicted baseflow assessment

Component	All river features	Carmichael River
Baseflow percentage change (%)- long term post closure		

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6 Response to past model review criticisms

Following submission of the initial and supplementary EIS, the conceptual hydrogeological model and numerical groundwater flow model have been reviewed by a range of scientists. A summary of review elements has been previously compiled and documented in EMM 2022. Individual comments and recommendations are presented in Table 6.1 along with our responses following model design, history match, predictions and uncertainty analysis.

Table 6.1 Approach to address past project criticism

Author/reference	Summary of comments	Data/research/approach
URS 2013b	<p>Field data could have been better integrated into conceptual model, to determine a set of preferred values and ranges for hydraulic conductivity and storage.</p> <p>No storage calibration from steady state model – literature values used.</p> <p>Water balance with high recharge loss.</p> <p>Heterogeneous hydraulic conductivity across layers.</p> <p>Issues raised include: Cumulative percentage discrepancy, stream leakage and baseflow, model parameter variation due to longwall mining, and post closure water balance.</p> <p>Geology – the cross section indicates uniformly dipping units to the west, and noted that groundwater flow patterns across the site are contrary to the dip of the units.</p> <p>Are higher potentiometric pressures to the north and south considered for the flow in the report, are enhanced recharge, or structures considered?</p> <p>Suggested that hydraulic connection between the Permian target coal and the GAB be added, querying the potential for faults that could connect the Clematis Sandstone to the Permian unit thus impacting on the GAB.</p> <p>The recharge rates to the Galilee Basin confined Permian units are not well detailed and are incomplete, additional details are required for the confined aquifers and what rates were included across the model domain. Surficial geology has recharge rates of 0 to 44 mm/yr, while modelling used rates of 0.1 to 5mm/yr.</p> <p>It is considered that additional discussion regarding flow patterns, on and adjacent to the mine lease, is required as these flows are contrary to the dip of the geology. Consideration of different flow directions in the Galilee Basin units and GAB units, groundwater divide and groundwater low points north of the Carmichael River.</p> <p>Groundwater flow in the Clematis Sandstone needs to be included in the conceptual model, to indicate flow pattern differences in the GAB units and Galilee Basin units.</p>	<p>Hydrogeological conceptualisation has been updated to address the key issues raised by this document, including:</p> <ul style="list-style-type: none"> • Drilling and installing monitoring sites to the west of the lease area to provide geological control and to assess Triassic and Permian pressures in the vicinity of the DSC to establish source aquifer. • New geological mapping in the area to the west of the mine lease near the DSC. • New field and laboratory measurements of K and S for the Rewan, Dunda and Clematis HSUs. Detailed analysis of Kx and Kz with depth across the Rewan aquitard. Integrated K datasets have established field-based statistical ranges for each HSU. • The GAB Springs research program and Rewan connectivity research program have produced updated potentiometrics and vertical flow gradients using contemporary data. • A comprehensive hydrogeochemistry and isotopes analysis program has confirmed a Triassic source aquifer for the DSC. • A comprehensive surface water-groundwater investigation has been undertaken to inform the updated HCM and groundwater model. • This revised HCM has undertaken statistical trend analysis on over 100 monitoring locations to identify any potential dewatering impacts in each main HSU. This trend analysis provides direct feedback on how each HSU is responding to over two years of dewatering in the Permian Betts Creek Beds. • Updated nested hydrograph analysis has provided insights on the vertical hydraulic gradients across the site and helped to better understand the mechanisms for DSC discharge, the extent of artesian heads in the Clematis, Dunda Beds and upper Rewan formations, and the impacts of landholder pumping and dewatering on the Permian HSUs. • The Rewan connectivity research program has included review of field data, lithofacies interpretation, interpretation of groundwater resources, detailed analysis of hydraulic

Table 6.1 Approach to address past project criticism

Author/reference	Summary of comments	Data/research/approach
	<p>The Rewan Group as a unit is important for model predictions on the GAB, additional discussion on the sensitivity results should be provided.</p> <p>No source of data or assumptions on the geology outside of the mine lease.</p> <p>Model convergence criteria might be too high at 1×10^{-2} m, typically 1×10^{-3} m is used.</p> <p>Elevated water balance errors in some stress periods of the predictive model represents a genuine shortcoming of the current model.</p> <p>Does hydraulic conductivity vary with depth?</p> <p>The calibration does not show if the vertical hydraulic gradients were preserved at locations that had multi nested monitoring points.</p> <p>No transient calibration was performed, storage parameters were selected from literature values, effects from river stage changes show a change of several meters, can the steady state model be representative?</p> <p>How were SW/GW interactions assessed in the steady state model for the dry season outside of the mine lease?</p> <p>Please explain how the recharge rate was determined and provide discussion on the effective recharge.</p> <p>Please explain how a robust predictive model can be generated from the current steady state model calibrated to average head data only.</p> <p>Hydraulic conductivity distribution was used for Layers 9 to 12, rather than a uniform value used, resulting in a bull's eye value in one area. Show the distribution and comment on values.</p> <p>A low value of residual saturation was used for the unsaturated zones at 5×10^{-3}.</p> <p>Large mass balance errors were identified at some stress periods, as such the predictive model outcomes are questioned.</p> <p>Horizontal and vertical hydraulic conductivities and storage parameters were not increased for the mined coal seam (the goaf) after mining. Only the vertical hydraulic conductivity was increased for the layers above goaf. The impact of dewatering could be underestimated. Changes to the coal seam parameters is recommended.</p> <p>Water balance needs further discussion, for the post-closure modelling and for the discharge to other water courses, in addition to the error difference. Predicted baseflow impacts require further discussion as rates are different in tables and figures.</p> <p>A mine plan with schedule was not provided. For a 5 year mine plan, how was it applied, equally in yearly increments?</p> <p>No uncertainty analysis was detailed or discussed in the report, an uncertainty analysis could provide additional confidence in model predictions with</p>	<p>properties, reprocessing of seismic data, mapping and modelling of fault styles, fault juxtaposition analysis, shale gouge & fault membrane seal analysis, assessment of fault leakage potential, assessment of longwall subsidence on hydraulic properties. These studies have indicated that the Rewan aquitard is a competent aquitard at the site with no potential for natural flow pathways to hydraulically connect the Triassic and Permian formations. The study did identify the key risk for hydraulic connection is related to mine-induced longwall subsidence.</p> <p>Planned updates to groundwater flow model (GWFM):</p> <ul style="list-style-type: none"> • Sensible modelled fluxes and low water balance errors cumulatively and for discrete time intervals • Transient calibration, including flux targets for SW-GW interactions as per Section Error! Reference source not found. • Highly parameterised approach to calibration, with parameter bounds guided by (but not restricted to) field data • Hydraulic conductivity reduction with depth in accordance with Section Error! Reference source not found., nominally for Rewan Formation but also for other HSUs if supported by observed data • Presentation of modelled vertical hydraulic gradients • Detailed calibration sensitivity analysis • Time-varying material properties to include mined coal seam, not just layers above goaf • Type 3 predictive uncertainty analysis

Table 6.1 **Approach to address past project criticism**

Author/reference	Summary of comments	Data/research/approach
	<p>regards to: storage, hydraulic conductivity and storage after longwall mining, groundwater ingress, and climate change.</p> <p>Recommendations:</p> <ul style="list-style-type: none"> • Clear description of the conceptual model. • Provide a summary of model approaches, objectives and model level. • Validate the location and type of boundaries. • Calibrate the model with transient head targets, flow data, that preserve the vertical head gradients. • A review of the model mass balance as it includes negative recharge. • Improve the cumulative percentage error to be under 1%. • Discuss the flow component of the model. • Conduct a sensitivity analysis for the transient predictive model. 	
GHD 2013	This report does not contain any model criticisms or recommendations.	N/A
IESC 2013	<p>Important data gaps exist in the groundwater flow conceptualisation, especially in the deeper groundwater systems, most notably hydraulic head information. The interpretation is not considered to be consistent with expected groundwater flow for deeper formations, given regional geology and accepted regional groundwater flow directions within the GAB. insufficient data provided in the draft SEIS to substantiate the proponent's groundwater flow conceptualisation.</p> <p>The current groundwater model assumes the Rewan Formation will respond uniformly as an aquitard. More data are needed to predict the effect of potential subsidence induced fracturing in the Rewan Formation on leakage rates from the GAB to the coal seam. Information on the degree of groundwater connectivity between the coal seams and the GAB is essential to understand the potential impacts of this project.</p> <p>The source aquifer for the Mellaluka Springs Complex has not been determined, and as such it is not possible to accurately predict impacts from mining on these Springs. For both the Mellaluka and Doongmabulla Springs Complexes there is insufficient information on ecology and water chemistry. The Committee has little confidence in the capacity of the groundwater flow conceptualisation and groundwater flow model to predict the impact on these Spring Complexes.</p> <p>The proponent undertook a limited cumulative impact assessment including four other proposed projects in the region. There are, however, additional relevant proposed projects which should be included.</p>	<p>Hydrogeological conceptualisation has been updated to address the key issues raised by IESC, including:</p> <ul style="list-style-type: none"> • Drilling and installing monitoring sites to the west of the lease area to provide geological control and to assess Triassic and Permian pressures in the vicinity of the DSC to understand the deeper flow systems, the pressure gradients across the Rewan and to establish the source aquifer for the DSC. It is commonly accepted that flow moves up-dip in the Surat Basin on the northern side of the range due to discharge at the Dawson River and springs. Similarly, at the project site east of the groundwater divide, there is up-dip flow towards discharge locations at the project area. This is discussed in detail in Section 7. • Subsidence-induced fracturing was a major component of the Rewan connectivity research program. Findings from that research have informed the revised HCM in this report. • The GAB Springs Research program is leading to more defined understanding of how the DSC functions. New monitoring bores and VWP's and hydrochemical and isotopes surveys have identified that the Clematis Sandstone is the source aquifer for the springs. Nested sites at the springs and downstream of the springs have shown that the Clematis Sandstone is strongly artesian in this area and is likely restricted to the east, which is driving artesian pressure build up behind that restricted flow outlet. This is leading to pressures building up over geological time and driving discharge to those springs.

Table 6.1 Approach to address past project criticism

Author/reference	Summary of comments	Data/research/approach
	<p>The conceptual model would benefit from an assessment of regional faults.</p> <p>The Committee is not confident that the proponent's groundwater model will be able to accurately predict responses to perturbation of the groundwater system arising from the proposed mine.</p> <p>The Committee has significant concerns in relation to the use of no flow boundaries at most of the edges of the model domain and the truncation of the Clematis Sandstone (and other geological formations) on the western side in the numerical model. The Committee challenges the model boundaries, and the use of no flow boundaries without justification, as it might have profound effects on the model's predictions.</p> <p>The assessment of the height of the subsidence fracture zone above longwall mining was not based on local site data nor with due consideration of multi-seam mining. The connectivity of the fracture network and the relative increase in hydraulic conductivity of strata within this zone needs verification. Subsidence fracture zone height and hydraulic connectivity could have implications for the predictive results.</p> <p>The proponent's field data needs to be further integrated into the groundwater model to establish an appropriate set of values and ranges for model layers' hydraulic parameters for the Rewan Formation. The implications of an increase in the permeability of the Rewan Formation and variations to the local geology and the effects on regional groundwater processes need to be further explored.</p> <p>There remain important data gaps and modelling inaccuracies which bring into question the hydraulic conductivity values employed by the model.</p> <p>However due to uncertainty around model parameters for hydraulic conductivity and the characterisation of the Rewan Formation, conclusions on impacts to the GAB and springs need to be reconsidered.</p> <p>Revision of the groundwater model and more in-depth spring surveys to enable a more rigorous assessment of potential impacts on the Doongmabulla and Mellaluka Springs Complexes.</p> <p>The development of an appropriately scaled regional groundwater model and water balance, commensurate to the size of the development, to reduce uncertainty in regard to cumulative impacts.</p> <p>The conceptual groundwater model is not adequate nor underpinned by sufficient representative data. There is insufficient hydraulic head information, particularly in the deeper geological units.</p> <p>Due to inappropriate boundary conditions the Committee has no confidence in the results of the groundwater model. The Committee considers that the revised groundwater model is not adequate to assess the potential impacts.</p>	<ul style="list-style-type: none"> • The conceptual model has drawn on the Rewan research into fault behaviour at site and how this may influence Rewan connectivity. This includes dedicated research on reprocessing of seismic data, mapping and modelling of fault styles, fault juxtaposition analysis, shale gouge & fault membrane seal analysis, and assessment of fault leakage potential. • New field and laboratory measurements of K and S for the Rewan, Dunda and Clematis HSUs. Detailed analysis of Kx and Kz with depth across the Rewan aquitard. Integrated K datasets have established field-based statistical ranges for each HSU. <p>Planned updates to GWFM:</p> <ul style="list-style-type: none"> • Calibrated parameters to be more closely tied to field data (ie Section Error! Reference source not found.) • Additional justification on regional boundary conditions, potential sensitivity analysis on no flow boundaries • Detailed uncertainty analysis incorporating potential connectivity between the GAB and the coal seams based on RP5

Table 6.1 Approach to address past project criticism

Author/reference	Summary of comments	Data/research/approach
	<p>Groundwater flow in deeper aquifers would be anticipated to conform to the generally recognised regional westerly flow within the GAB from the eastern recharge zone towards the centre of the basin. The independent peer review of the groundwater model undertaken by URS also notes that the model flow direction is at odds, and is not consistent, with the regional flow direction and geology.</p> <p>The URS review of a draft version of the groundwater model recommends that the proponents validate the location and type of boundaries in the model.</p> <p>The model truncates geology on the western side of the numerical model, the no flow boundary condition employed forces the numerical model to indicate groundwater flow towards the Carmichael River based on limited available bore data.</p> <p>No-flow boundaries (particularly for the Triassic and Permian hydrogeological units) in the model need to be justified and appear to be based on the surface water catchments. As a consequence, the Committee has no confidence in the predicted groundwater flows in the Permian and Triassic Formations.</p> <p>There is uncertainty around the capacity of the Rewan Formation to act as an aquitard to limit vertical leakage between adjacent formations. Mean values of hydraulic conductivity are recommended to be used. The formation does not take into consideration any potential of faulting.</p> <p>The Committee is not confident that the proponent's groundwater model, based on the current conceptualisation will be able to accurately predict responses to perturbation of the groundwater system arising from the proposed mine.</p>	
Hydrogeologic 2014	<p>Transient calibration has not been undertaken, which is a model shortcoming that has been addressed via comprehensive sensitivity and uncertainty analysis.</p> <p>To improve the match of three bores in the southern Clematis outcrop would require increased recharge in this key area, and/or aquifer parameter changes, plus contemporaneous groundwater monitoring data for model validation, which is recommended for future investigation.</p> <p>The model stress period arrangement indicates annual increments for the first five years, which is acceptable; however, subsequent stress periods are 5-yearly to 2049, then 10-yearly to 2059, which is possibly a little coarse but not unreasonable; future modelling programs should review and/or refine this arrangement by testing model sensitivity to refined stress periods (no more than 1-2 years).</p> <p>Future model work programs are recommended to investigate refinements of the recharge to improve the match to southern Clematis water levels and to investigate the flow system in the Lake Galilee area. To improve the model matches at these three key</p>	<p>Hydrogeological conceptualisation has been updated to address the key issues raised by Hydrogeologic, including:</p> <ul style="list-style-type: none"> • Increased monitoring sites in the Clematis Sandstone west of the lease area to better understand flow dynamics in this GAB aquifer. A thorough review of long-term groundwater levels and vertical gradients has provided insights that suggest the Clematis Sandstone is artesian to the west of Surprise Creek and that a flow restriction occurs near Surprise Creek that reduced the eastern flow component of the aquifer sufficiently to raise pressures in this formation to the west. These artesian pressures then drive discharge to the springs. • Drilling and installing monitoring sites to the west of the lease area to provide geological control and to assess Triassic and Permian pressures in the vicinity of the DSC to understand the deeper flow systems, the pressure gradients across the Rewan and to establish the source aquifer for the DSC.

Table 6.1 Approach to address past project criticism

Author/reference	Summary of comments	Data/research/approach
	<p>Clematis bores would require increased boundary inflows from the south and/or increased rates of modelled Clematis recharge, and/or aquifer parameter changes.</p> <p>Ongoing investigations and monitoring in the area of groundwater flow from the south to north, and a significant flow to the west (and GAB) area are required to provide data for future validation of the model in terms of layer elevations and properties for aquifers/aquitards (including geochemistry and isotopes), groundwater levels and quality and surface-groundwater interactions (notably river and spring flows/levels and geochemistry).</p> <p>It is recommended that model sensitivity be explored for inactive cells immediately east of the Clematis outcrop, and that this boundary condition be tested in the next model update by applying the “dummy layer/parameter” treatment to the currently inactive cells in layers 4 and above in this central area.</p> <p>It is suggested that layer 12 of the model be split into 2 separate layers, this model refinement would be required in the future to help investigate aquifer connectivity with Mellaluka Springs, where significant drawdowns have been predicted, in conjunction with the data that will be acquired from the three monitoring boreholes recently drilled in this area.</p> <p>An involuntary model error was discovered where hydraulic parameters were different on Layer 4 in the eastern half of the model domain. Model design should aim for the implementation of parameters that warrants refinement in the future to either ensure consistent parameter values across all layers that represent specific units (or to objectively justify the parameter values applied).</p> <p>Further to the drilling on the Rewan Group, further tests be undertaken (chemical and isotope testing of pore water samples from the preserved core) to provide formation-scale aquitard parameters for input to the model.</p> <p>Future investigations should consider applying appropriate episodic recharge volumes to short periods, perhaps using data from the very wet periods of 2010-11 and 2011-12 (rather than annual averages) to validate the model.</p> <p>Further investigation of vertical head gradients is recommended during future work programs, especially once additional data is obtained in relation to the influence of the Rewan aquitard.</p> <p>Future refinements should consider; Lake Galilee recharge/discharge features, eastern outflow boundary conductance parameter consistency across all aquifers, and evaporation rate assumptions and sensitivities for post-closure pit void.</p>	<ul style="list-style-type: none"> • The conceptual model has drawn on the Rewan research into fault behaviour at site and how this may influence Rewan connectivity. This includes dedicated research on reprocessing of seismic data, mapping and modelling of fault styles, fault juxtaposition analysis, shale gouge & fault membrane seal analysis, and assessment of fault leakage potential. • New field and laboratory measurements of K and S for the Rewan, Dunda and Clematis HSUs. Detailed analysis of Kx and Kz with depth across the Rewan aquitard. Integrated K datasets have established field-based statistical ranges for each HSU. • Updated nested hydrograph analysis has provided insights on the vertical hydraulic gradients across the site and helped to better understand the mechanisms for DSC discharge, the extent of artesian heads in the Clematis, Dunda Beds and upper Rewan formations, and the impacts of landholder pumping and dewatering on the Permian HSUs. • A comprehensive surface water-groundwater investigation has been undertaken to inform the updated HCM and groundwater model. <p>Planned updates to GWFM:</p> <ul style="list-style-type: none"> • Active modelled area to be reviewed and updated if necessary • Additional vertical refinement of model layers in the area of mining • Transient calibration to groundwater heads, including trends from environmental stresses and pumping as assessed in Section Error! Reference source not found. • Calibration to be undertaken as a combination of highly parameterised and zone-based, indicated by conceptualisation and data availability • Updated recharge information as per Section Error! Reference source not found., incorporating episodic recharge rates • Updated stress period durations to more appropriately represent mine plan • Explicit simulation of post-closure pit void, including time-varying material properties, direct incident rainfall and evapotranspiration surface based on pit base elevation

Table 6.1 **Approach to address past project criticism**

Author/reference	Summary of comments	Data/research/approach
GHD 2015	<p>The model covers an active model domain of approximately 8,600 square kilometres. Consequently, there are limited data across a large geographical area, and as mentioned in the bioregional assessment for the area published by CSIRO (Evans et al, 2014), very limited hydrogeological information is available for the model region.</p> <p>It is acknowledged limited calibration and stratigraphic data is available for the area outside of the mine lease, and techniques have been adopted to interpolate discrete observations across a broad area.</p> <p>Of the 168 realisations in the sensitivity analysis, only four were characterised as having a potentially significant change in impact and an insignificant change in model calibration (ie indicative of uncertainty that will require further investigations and data to resolve. These results apply to the hydraulic conductivity of the Tertiary clay in the vicinity of the Mellaluka springs complex, where three additional bores have since been drilled).</p> <p>As the project continues to evolve, the groundwater model will continue to be updated to reflect advances in understanding of the regional hydrogeological conditions.</p> <p>Limited data are available within the western region of the model to develop comprehensive conceptualisations regarding groundwater flow conditions, a point that is documented in the bioregional assessment for the area published by CSIRO (Evans et al, 2014).</p> <p>The following recommendations are provided to guide future investigations and modelling studies, which should also consider the recommendations provided by the independent reviews completed to date:</p> <p>Update calibration targets based upon subsequent groundwater level data collected over the model domain, particularly within the GAB units to the west of the mine.</p> <ul style="list-style-type: none"> • Re-calibrate the model, including transient calibration, using operational and regional monitoring data. • Review modelled discharge to the Carmichael River against the updated stream gauging data accrued over the period since the model development. • Incorporation of the weathered zone into the model. • Review of recharge parameters, particularly in the GAB units. • Update of the model to represent any revisions in the proposed mine plan, including pit sequencing, pit geometry, proposed dewatering methods and closure methods and timing. • Split the existing model layer 12 into two layers to provide separation between the early Permian basement and the D-seams underburden. 	<p>Hydrogeological conceptualisation has been updated to address the key issues raised by GHD (2015), including:</p> <p>Drilling and installing monitoring sites to the west of the lease area to provide geological control and to assess Triassic and Permian pressures in the vicinity of the DSC to establish source aquifer, and to better constrain regional groundwater flow systems.</p> <p>Planned updates to GWFM:</p> <ul style="list-style-type: none"> • Update to GWFM based on updates to HCM, including explicit representation of weathered zone as per Section Error! Reference source not found. • Enhanced vertical discretisation in the vicinity of the mine • Transient calibration with updated targets, including surface water discharge fluxes where available • Transient recharge fluxes representing climate during history-matching period • More detail in sensitivity and uncertainty analyses

Table 6.1 **Approach to address past project criticism**

Author/reference	Summary of comments	Data/research/approach
CSIRO 2019	<p>Thus the accuracy of the predicted river flows and impacts could be enhanced in future modelling work by calibrating river conductance values against reliable baseflow targets for the Carmichael River.</p> <p>The review found that the modelling used is not suitable to ensure the outcomes sought by the EPBC Act conditions are met.</p> <p>Comparison of the SEIS model and the two alternate re-run models shows that the location of the western model boundary has little impact on drawdown predictions. However, these re-runs were not calibrated, thus reducing confidence in the predictions that they make. A re-calibration is warranted to improve confidence in model predictions.</p> <p>The SEIS model includes the most recent calibrated parameter set developed for the Carmichael Coal Mine in 2013. Although, it must be noted that model errors increased from 4.5% RMS error reported for the SEIS model to 7.2% when compared to updated data following resurveying bore locations.</p> <p>Representation in the model of surface water flows for the Carmichael River over-predicts flows from the river into the groundwater. As a result the groundwater drawdown in the alluvium (Carmichael River GDEs) will be greater than the predicted model.</p> <p>Parameterisation of the Rewan Formation and Clematis Sandstone by the SEIS model. Calibrated hydraulic conductivity values for the Rewan Formation are very low compared with measured values, which minimises vertical water movement, and hydraulic conductivity values for the Clematis Sandstone are high, which increases the lateral transfer of water.</p> <p>The approach used to model potential impacts to the groundwater system due to mining indicates that the model will under-estimate the amount of drawdown predicted at the DSC and the Carmichael River GDE as a result of model representation of:</p> <ul style="list-style-type: none"> • The unrealistically high modelled flow in the Carmichael River. • Error in the bore heights used to calibrate the model. • Hydraulic conductivity in the Clematis Sandstone and Rewan Formation model layers. <p>Recommendations:</p> <p>Future updates of the model should also use stream flow as one of the calibration parameters;</p> <p>Guidance for uncertainty analysis should be considered in future model updates.</p> <p>Model updates should include recalibration, and clearly define bore reference levels, how they have changed over time and how these changes affect model prediction and performance.</p> <p>Recalibration should include revised bore heights to provide confidence that captured evapotranspiration</p>	<ul style="list-style-type: none"> • A comprehensive groundwater-surface water investigation has been undertaken to inform the updated HCM and groundwater model. This study has assessed both creek flows, creek interactions with groundwater, as well as spring typology and water balances. • New field and laboratory measurements of K and S for the Rewan, Dunda and Clematis HSUs. Detailed analysis of Kx and Kz with depth across the Rewan aquitard. Integrated K datasets have established field-based statistical ranges for each HSU. • Drilling and installing monitoring sites to the west of the lease area to provide geological control and to assess Triassic and Permian pressures in the vicinity of the DSC to establish source aquifer. A comprehensive hydrogeochemistry and isotopes analysis program has also independently confirmed a Triassic source aquifer for the DSC. <p>Planned updates to GWFM:</p> <ul style="list-style-type: none"> • Recalibration to all available data, including fluxes to surface water • Any changes in model bore heights to be documented • Calibration to assign parameters consistent with HCM • Sensitivity analysis to include relative composite sensitivity • Type 3 (Monte Carlo) predictive uncertainty analysis, including assessment of mining-induced hydraulic parameter changes

Table 6.1 **Approach to address past project criticism**

Author/reference	Summary of comments	Data/research/approach
	<p>is not limiting drawdown to the DSC and the Carmichael River GDE.</p> <p>Future model updates should use locally appropriate parameterisations.</p> <p>Sensitivity analysis undertaken for future model updates should seek to assess cumulative sensitivity.</p> <p>Future model updates should include analysis of the sensitivity of the model to parameter changes due to underground mining.</p> <p>To constrain the source aquifer(s) of the DSC, a more sophisticated statistical analysis of hydrochemistry data is required. This includes assessing a wider variety of groundwater and surface water analytes, as well as appropriate use of isotope hydrochemistry analysis.</p> <p>Installation of bores to monitor the groundwater system in the Dunda Beds and Rewan Formation (upper Rewan and lower Rewan) at existing monitoring points in the west of the central zone would allow an assessment of any dewatering impact propagating through the Rewan Formation (in effect, nested monitoring bores). Ideally all units from outcrop to sub-Joe Joe coal (Jericho Formation) would be monitored.</p> <p>It is strongly recommended that the monitoring program includes stream flow gauging upstream and downstream of the mine area. Additionally, an improved and re-calibrated flow-discharge relationship for each gauge would improve the accuracy of the data.</p> <p>It is not plausible and reasonable to state unequivocally that the Clematis Sandstone is the sole source aquifer for the DSC, as sufficient uncertainty surrounding hydrogeochemistry, inter-aquifer connectivity and groundwater flow (Currell et al., 2017; Lewis et al., 2018; Webb et al., 2015) exists to necessitate a precautionary approach to the conceptualisation, as ruled by Land Court of Queensland (2015).</p>	

7 Summary and recommendations

The main summary points from the updated modelling study include:

- Model updated to meet Environmental Authority (EA) Condition E9, while addressing past review criticisms of the SEIS.
- Model rebuilt aligned with updated conceptualisation and datasets including geological model, groundwater pressures, groundwater drawdown and mine dewatering bore rates. Knowledge from Rewan Research and GAB Spring Research packages (i.e. spring conceptualisation and discharge volumes) incorporated.
- As noted by T Murray (2022), tying in the local Rewan Research model to the Bioregional assessment model highlighted some very significant mismatches and worrying errors. Murray recommended that a full review of the broader Bio-regional assessment model is warranted.
- Model history-matching and predictive uncertainty analysis used pilot points and PESTPP-IES with 500 parameter realisations developed.
- Results predict that the open cut (OC) only scenario will not breach the DSC drawdown threshold of 0.2 m for the base case or majority of ensemble of realisations.
- Although the OC basecase and the majority of realisations do not breach DSC drawdown thresholds, significant modelled drawdown emanates from the OC F and G pits. This is caused by the assumption that Clematis Sandstone exists in this region.
- Modelling of the SEIS mine plan using the previous model fracturing assumptions (Scenario A) associated with underground mining, results in base case drawdowns that do not breach the DSC 0.2 m drawdown threshold. These are comparable to the SEIS (2013) model results.
- Modelling of the SEIS mine plan using updated fracturing and relief zone assumptions (Scenario B), results in base case drawdowns that do breach the 0.2 m drawdown threshold, but only in the order of 5-10 cm.

The following recommendations are made:

- The groundwater system is complex, with vertical hydraulic gradients evident within the Clematis Sandstone. Further refinement to model layering within this unit may be required in future.
- Drawdown in the Clematis is exacerbated in the southern area of the mine, largely due to the interpreted/assumed geological layering. Further drilling is recommended to confirm the geology in this area (outcrop/subcrop, thickness and extent).
- Based on drilling outcomes, further Clematis, Bandanna and/or Colinlea monitoring bores may be required in the southern region to monitor drawdown impacts, which potentially could emanate from OC F and G pits. This is in addition to previously recommended bores to be installed in the western portion of the mining lease, east of the DSC.
- The model tends to simulate hydraulic heads higher than measured in regional discharge areas (i.e. heads <220 mAHD). Further investigation into this may be warranted to identify whether this is a regional throughflow process or whether groundwater may be discharging at greater rates within the model domain (e.g. greater evapotranspiration).

- A large amount of uncertainty remains associated with fracturing above and relief zone around, underground mining areas. Predictions appear to be sensitive to how these are simulated but, to date, there are no site data available to inform how the local system behaves. Updated knowledge, where available, should be used within the next 5-year model review with accompanied future predictive uncertainty analysis.
- Due to the current uncertainty associated with fracturing above and relief zone around, underground mining areas, it recommended that GMMP develops groundwater drawdown thresholds that are associated with the OC mining scenario only, at this stage.
- Future GAB Spring Research studies will concentrate on ecological water requirements (EWRs) of springs. Future modelling should include updated EWRs and associated thresholds.

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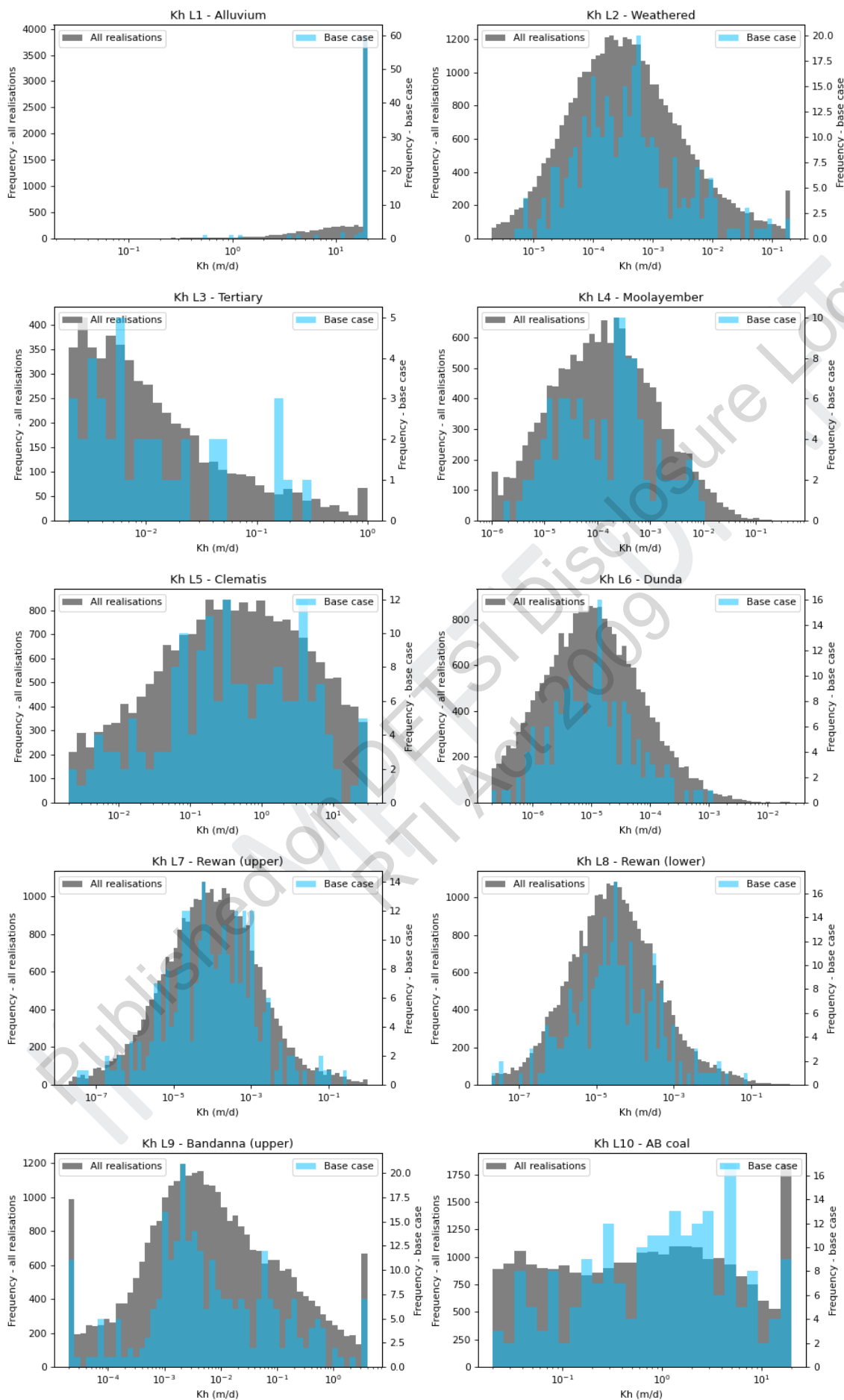
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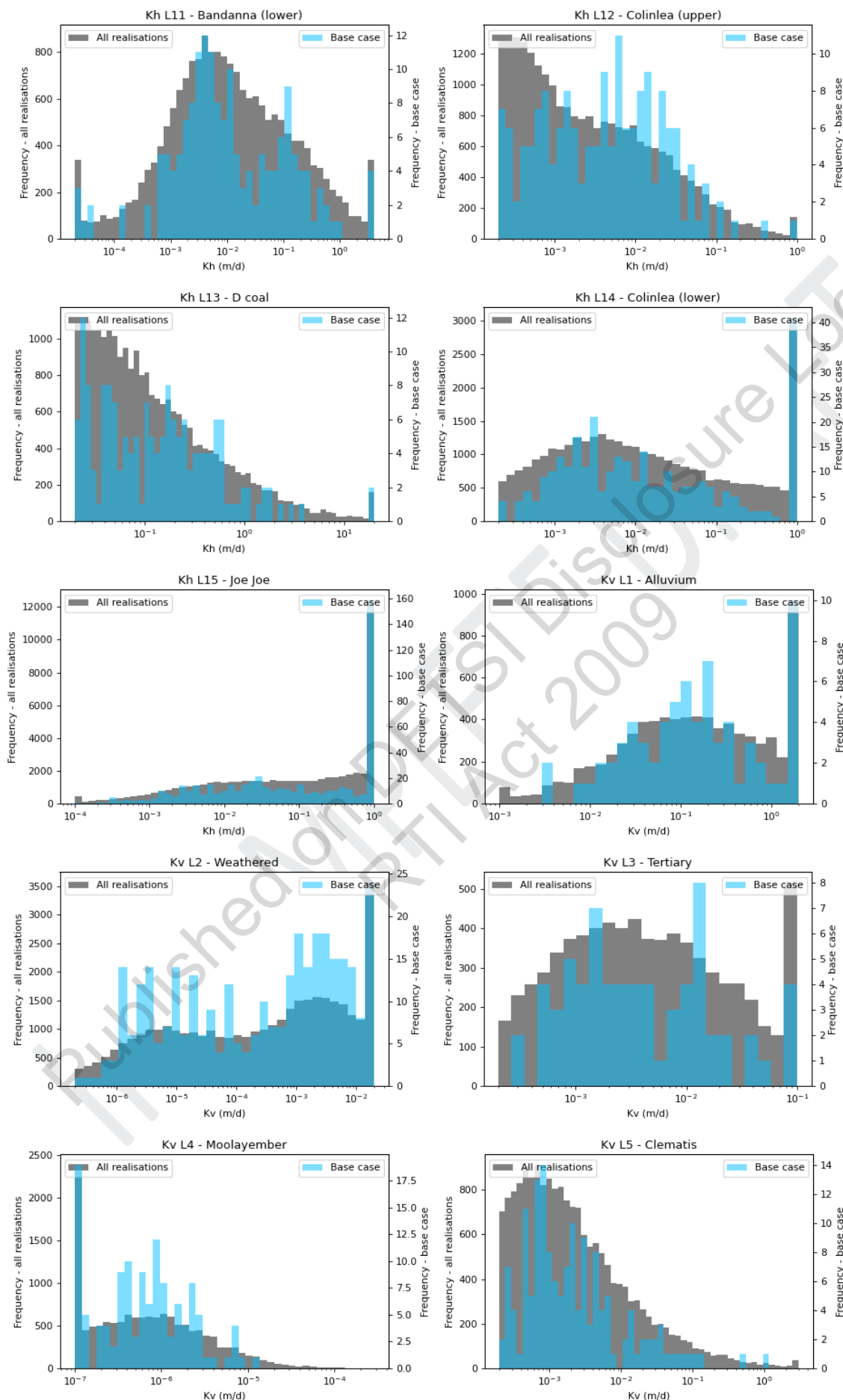
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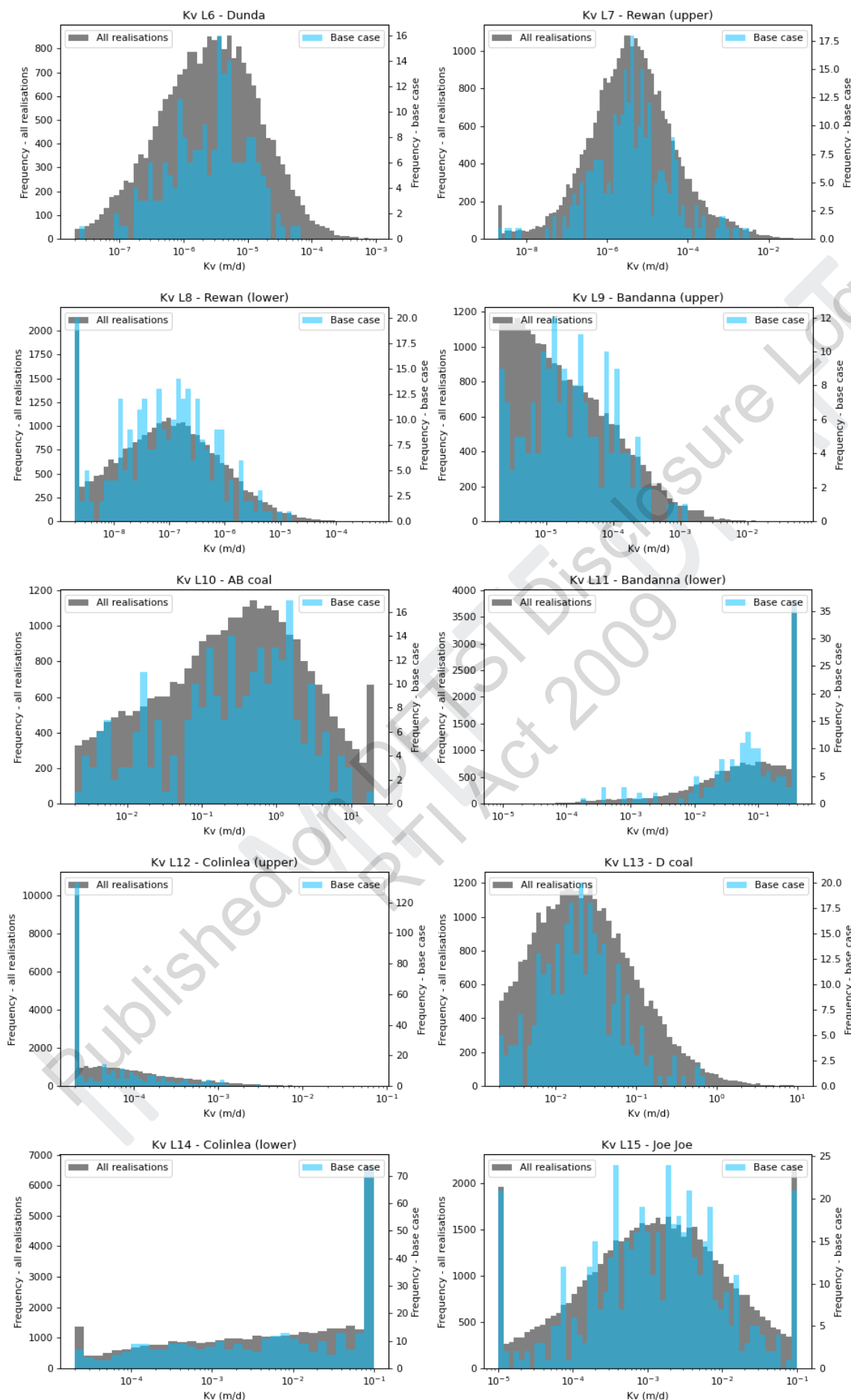
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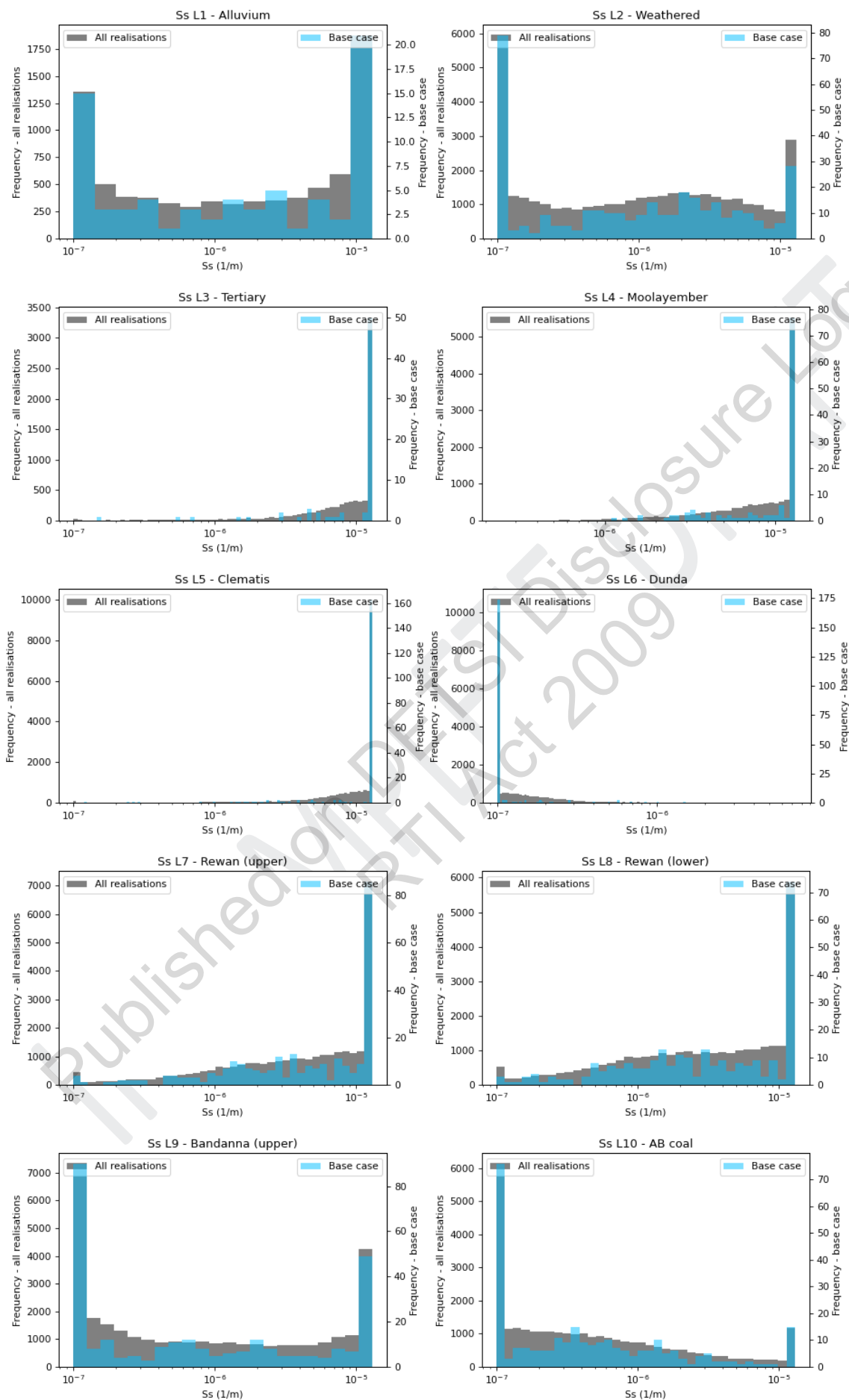
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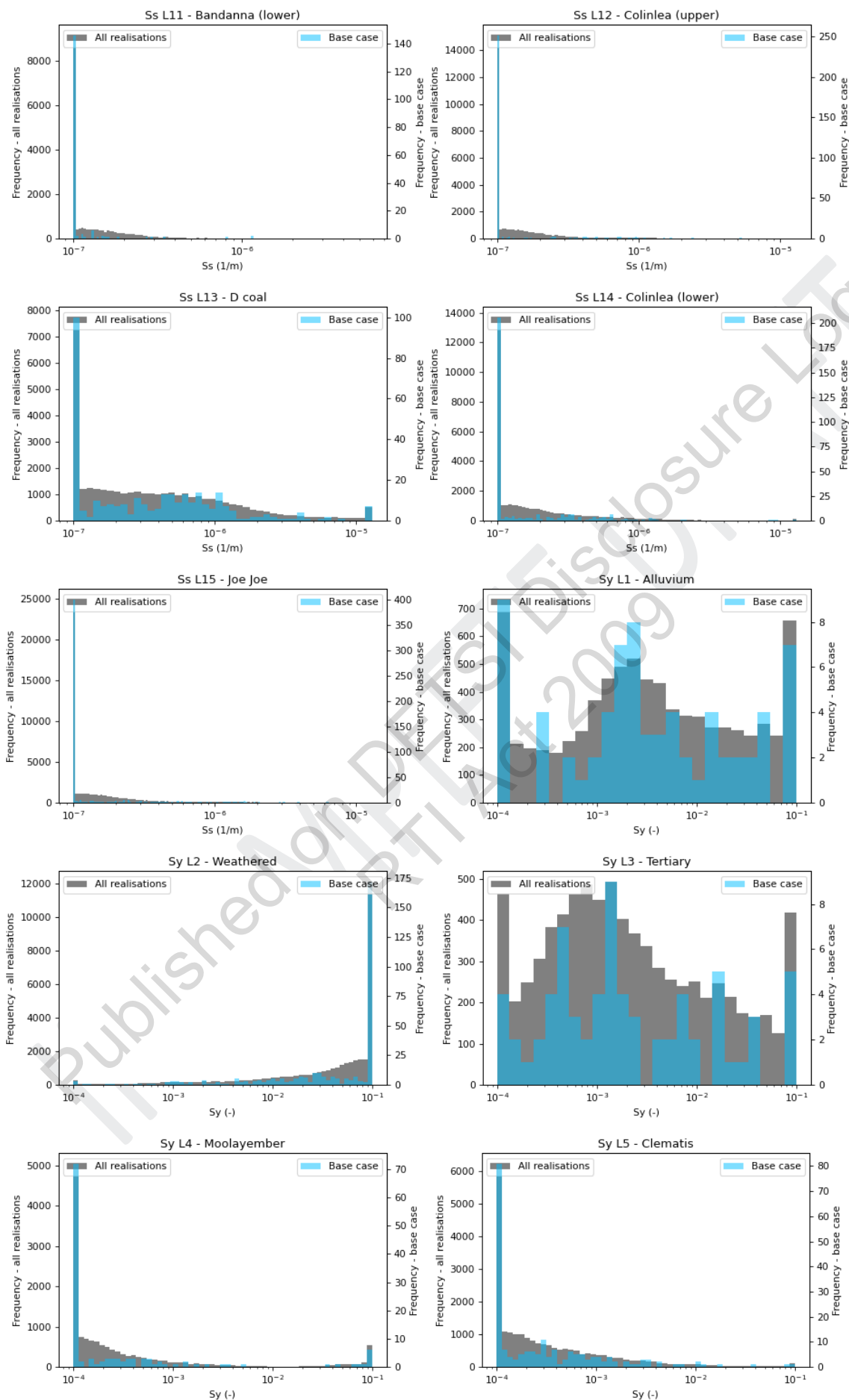
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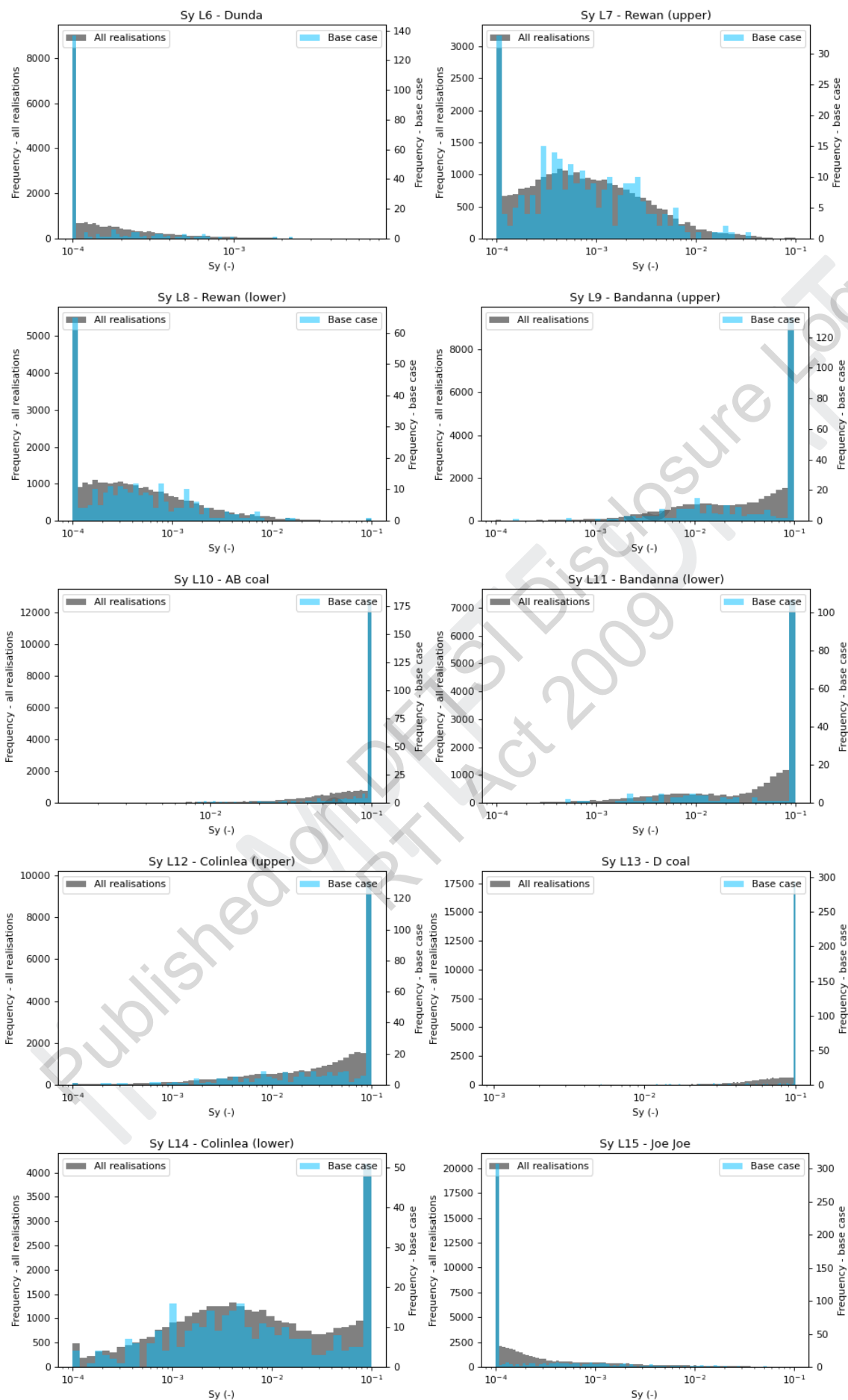


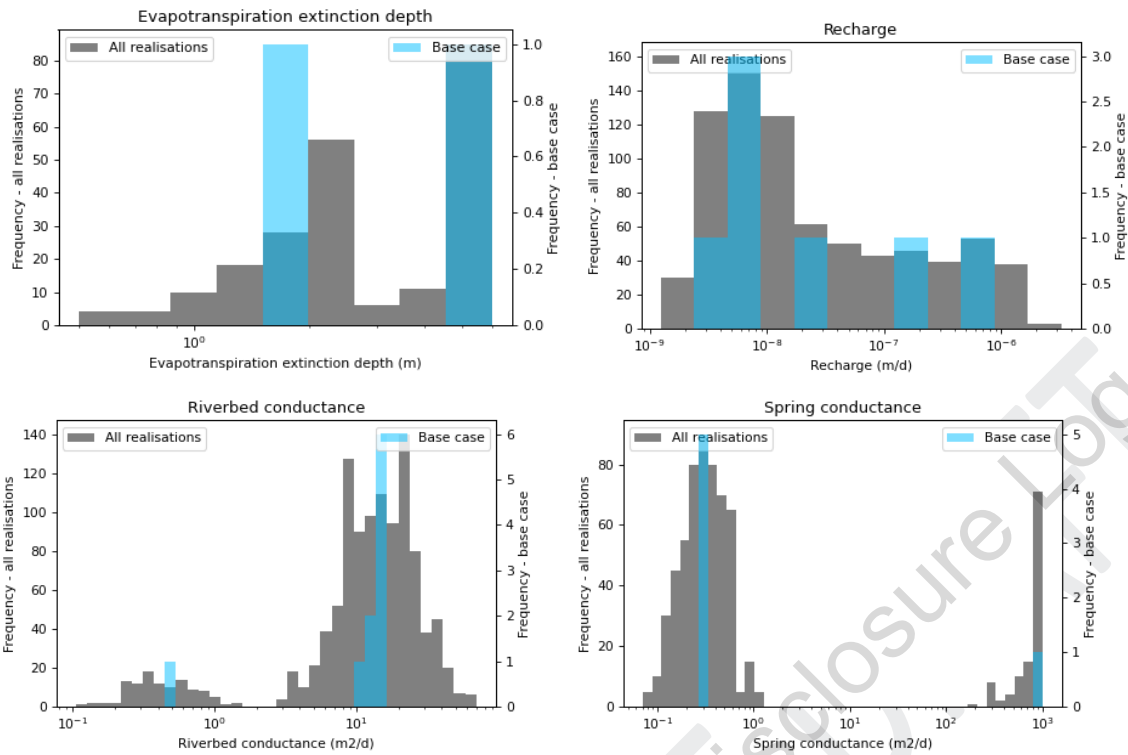








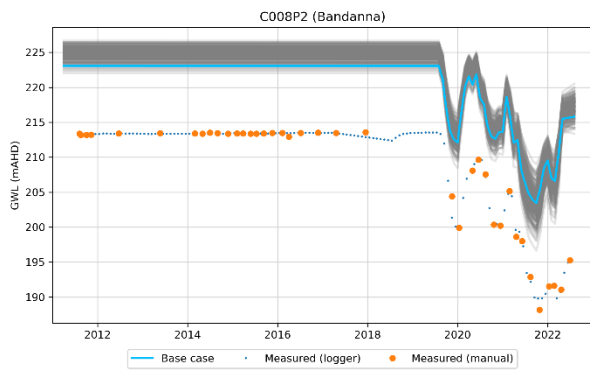
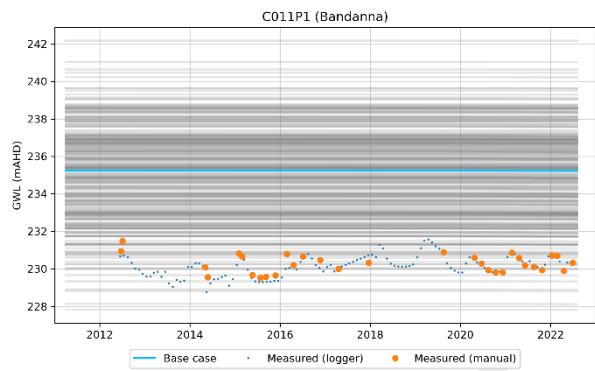
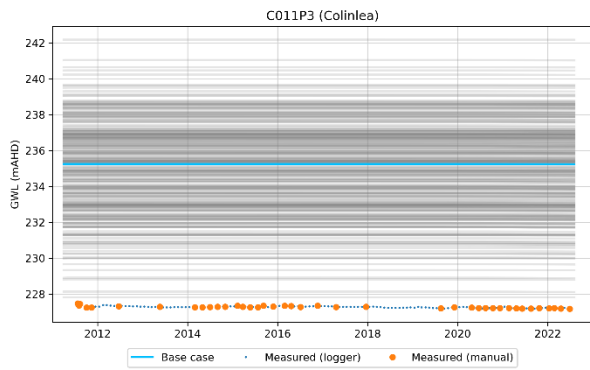
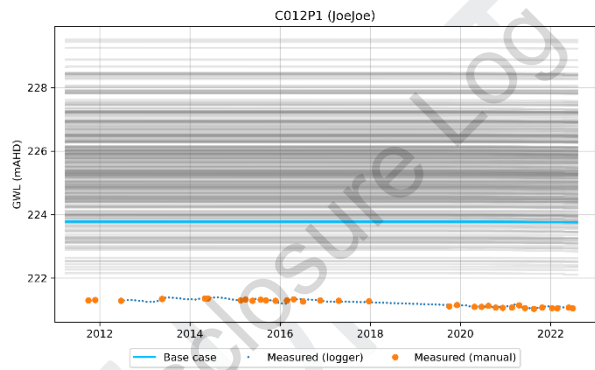
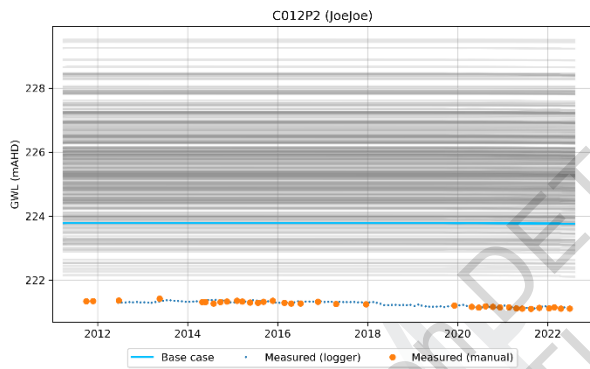
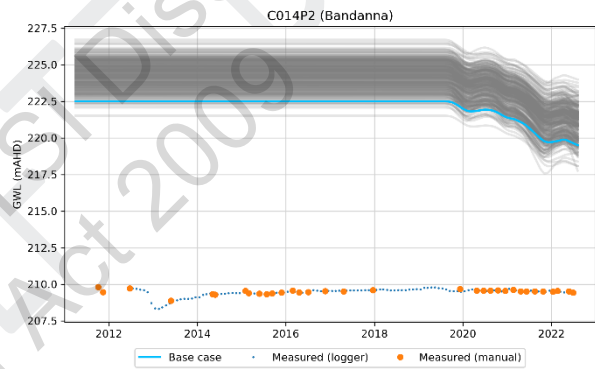
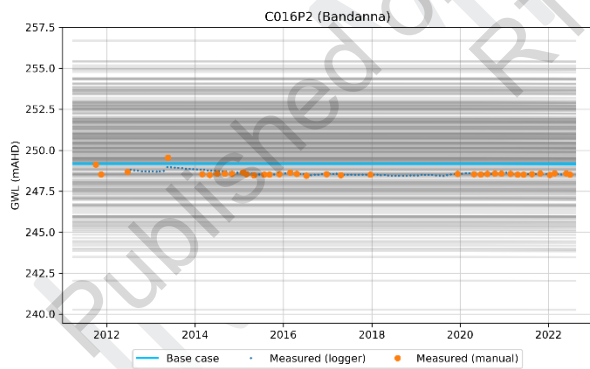
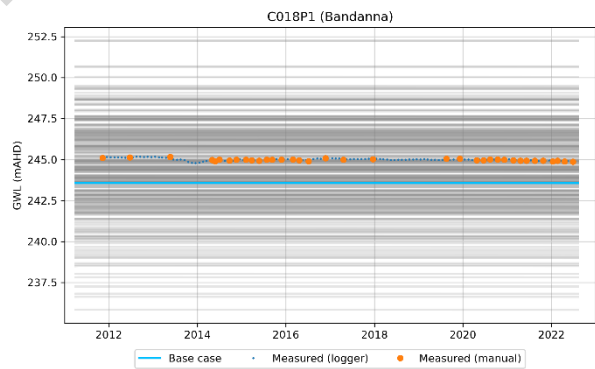
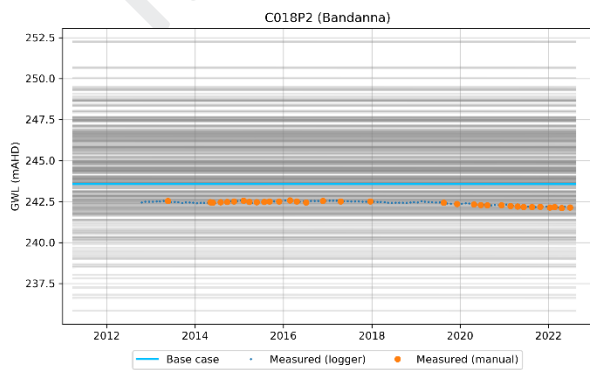
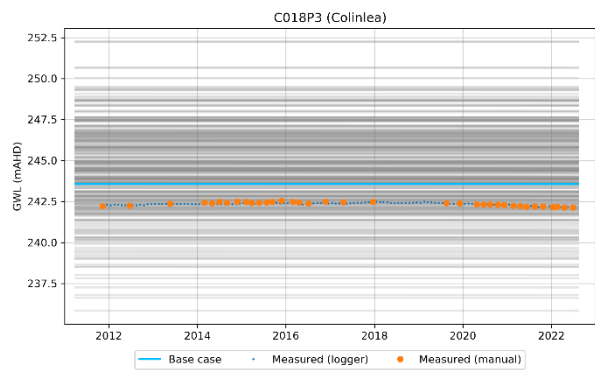




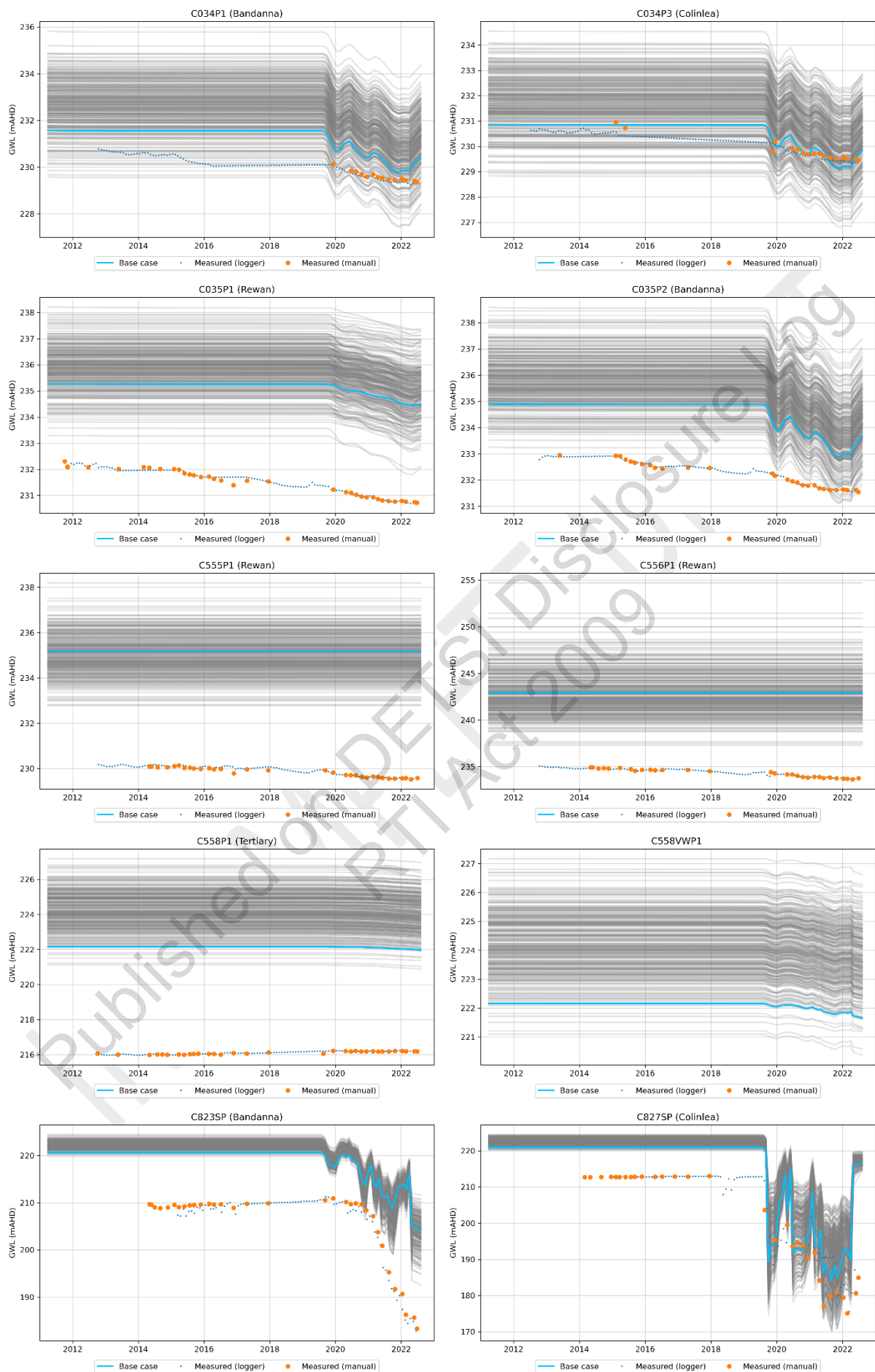
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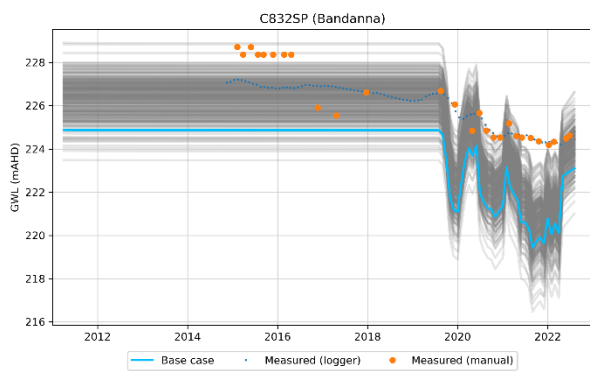
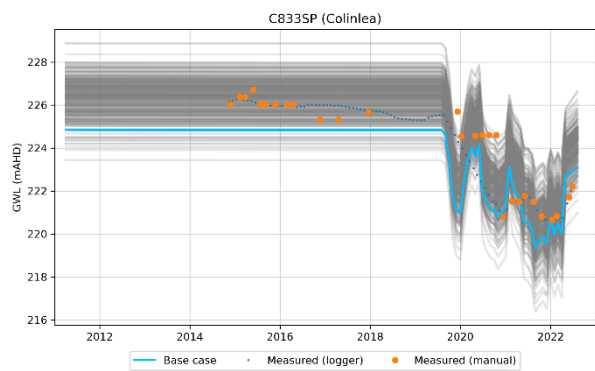
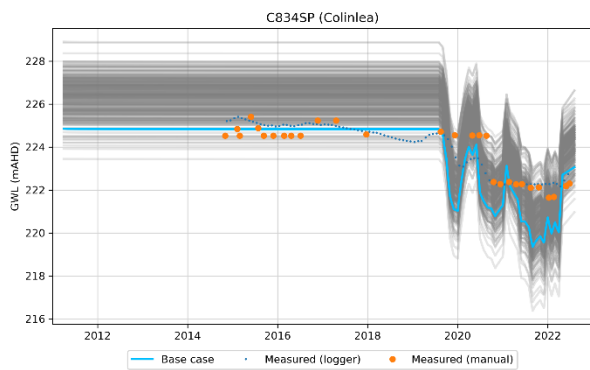
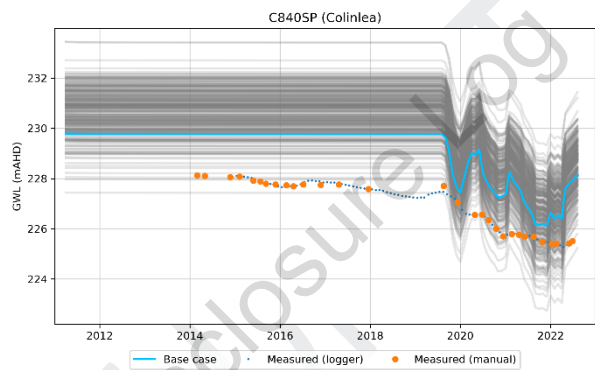
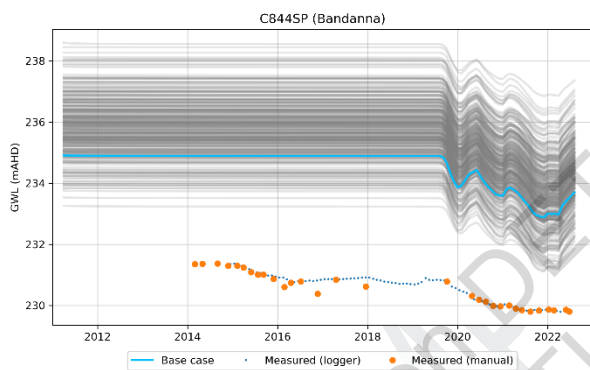
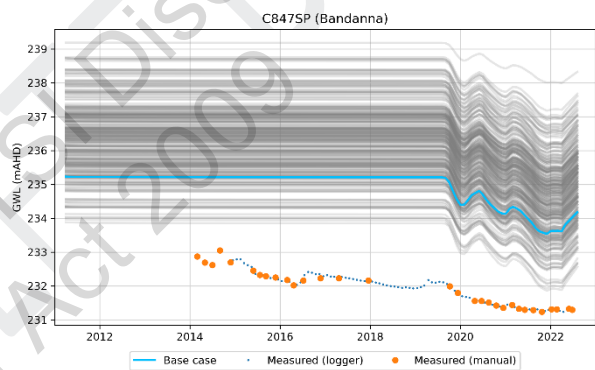
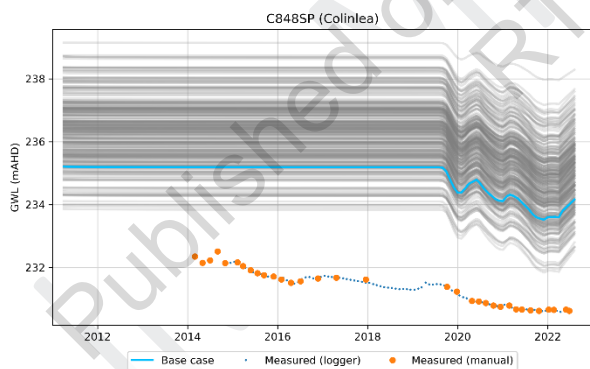
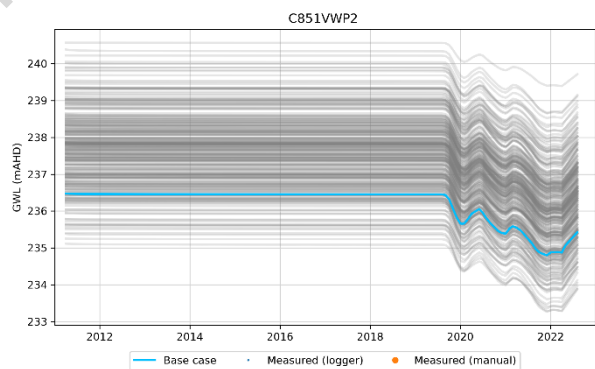
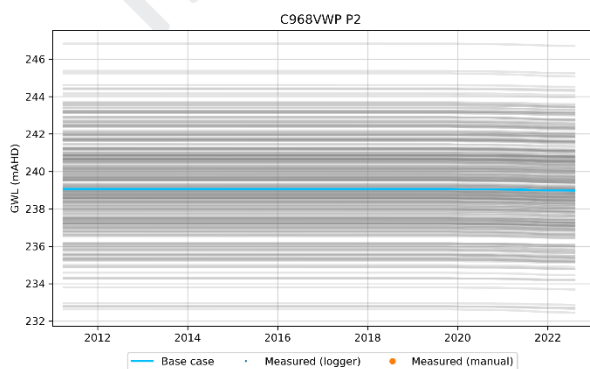
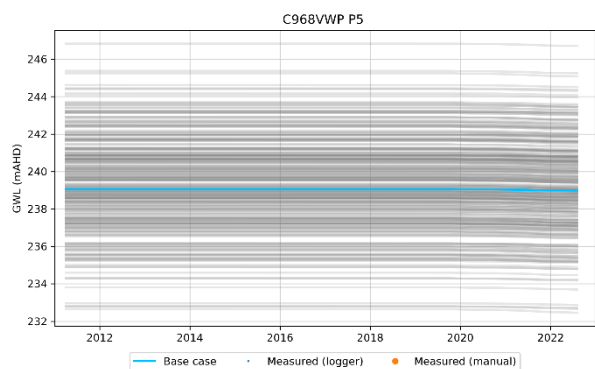
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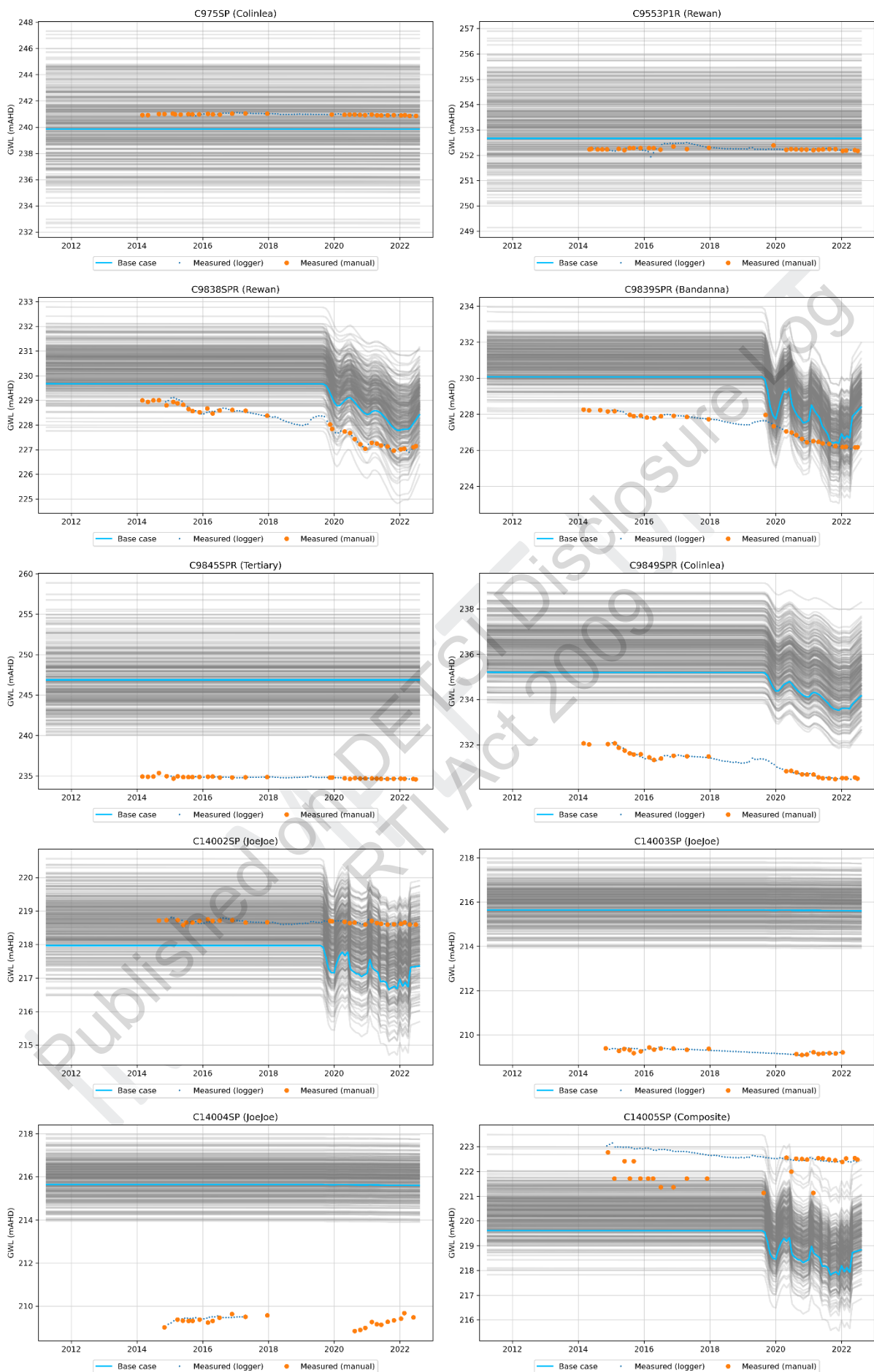


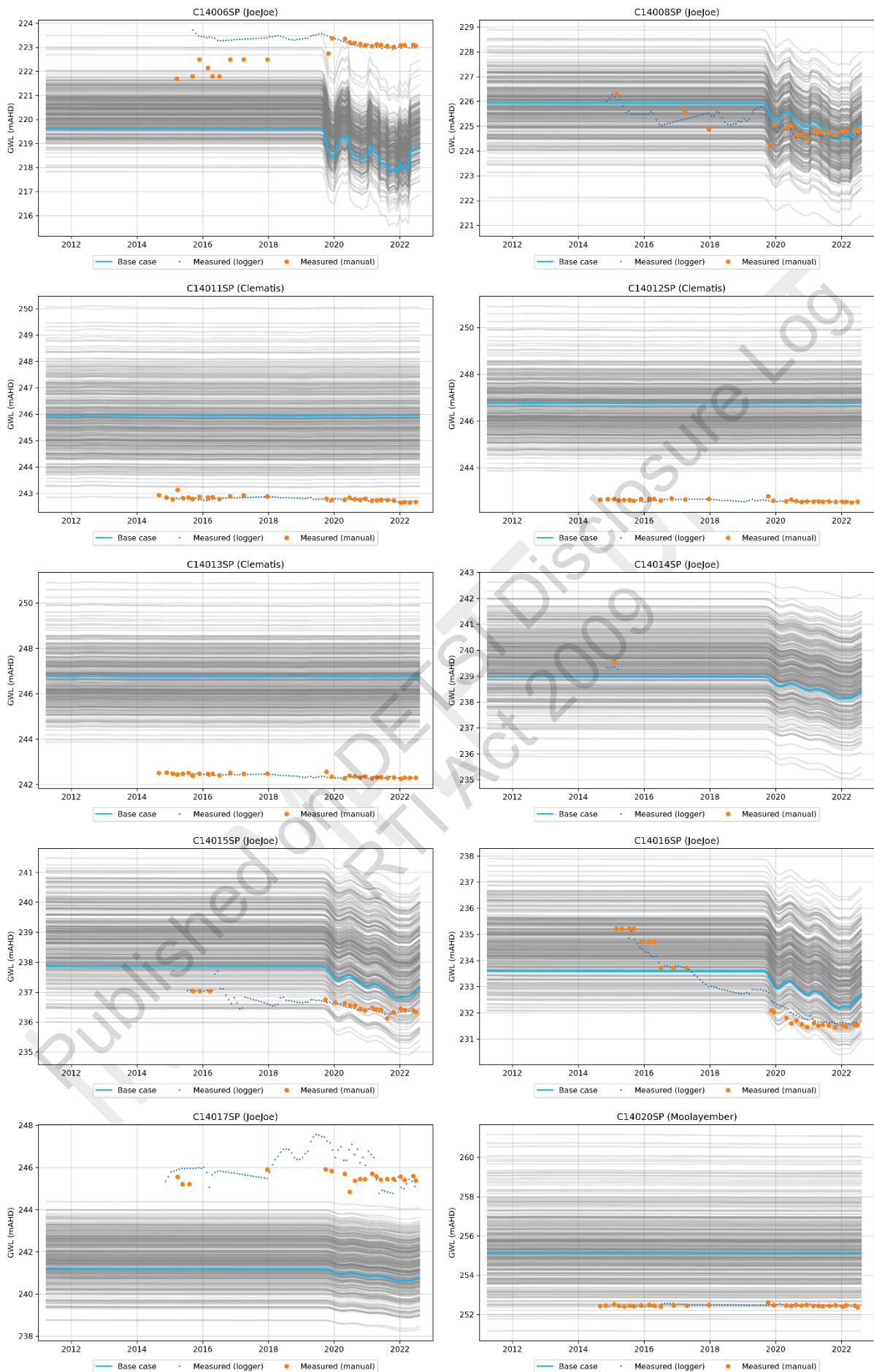


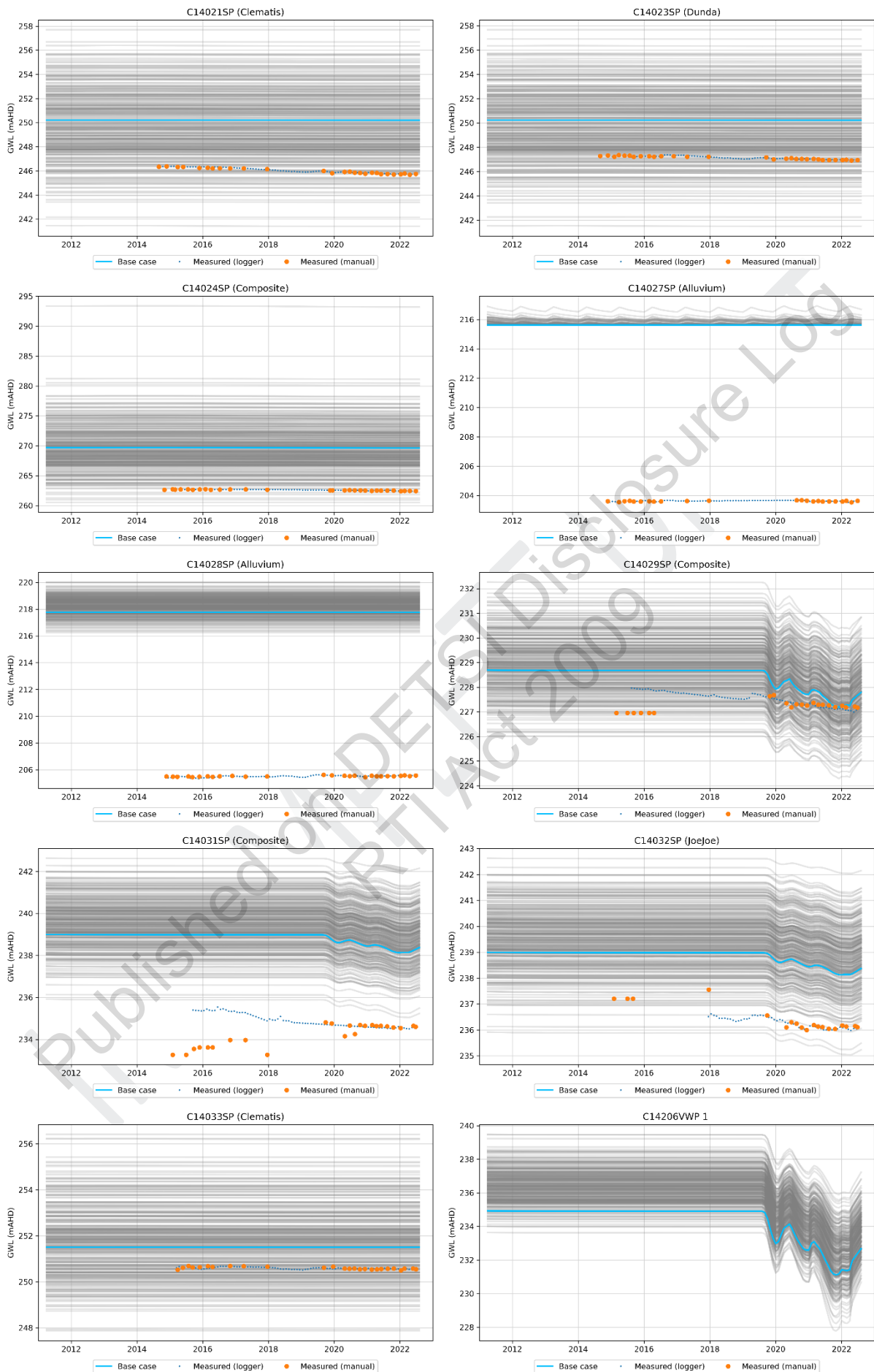


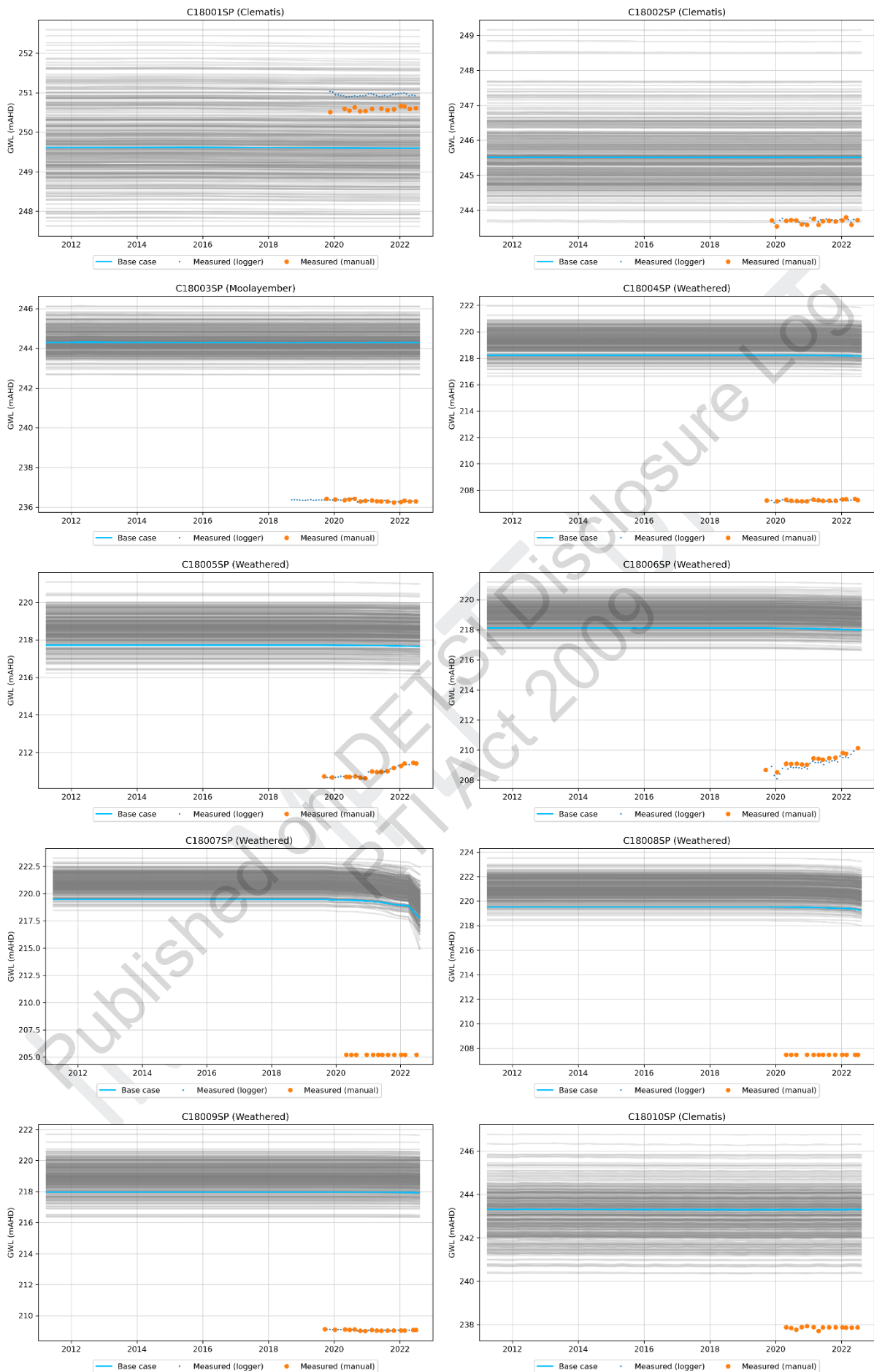


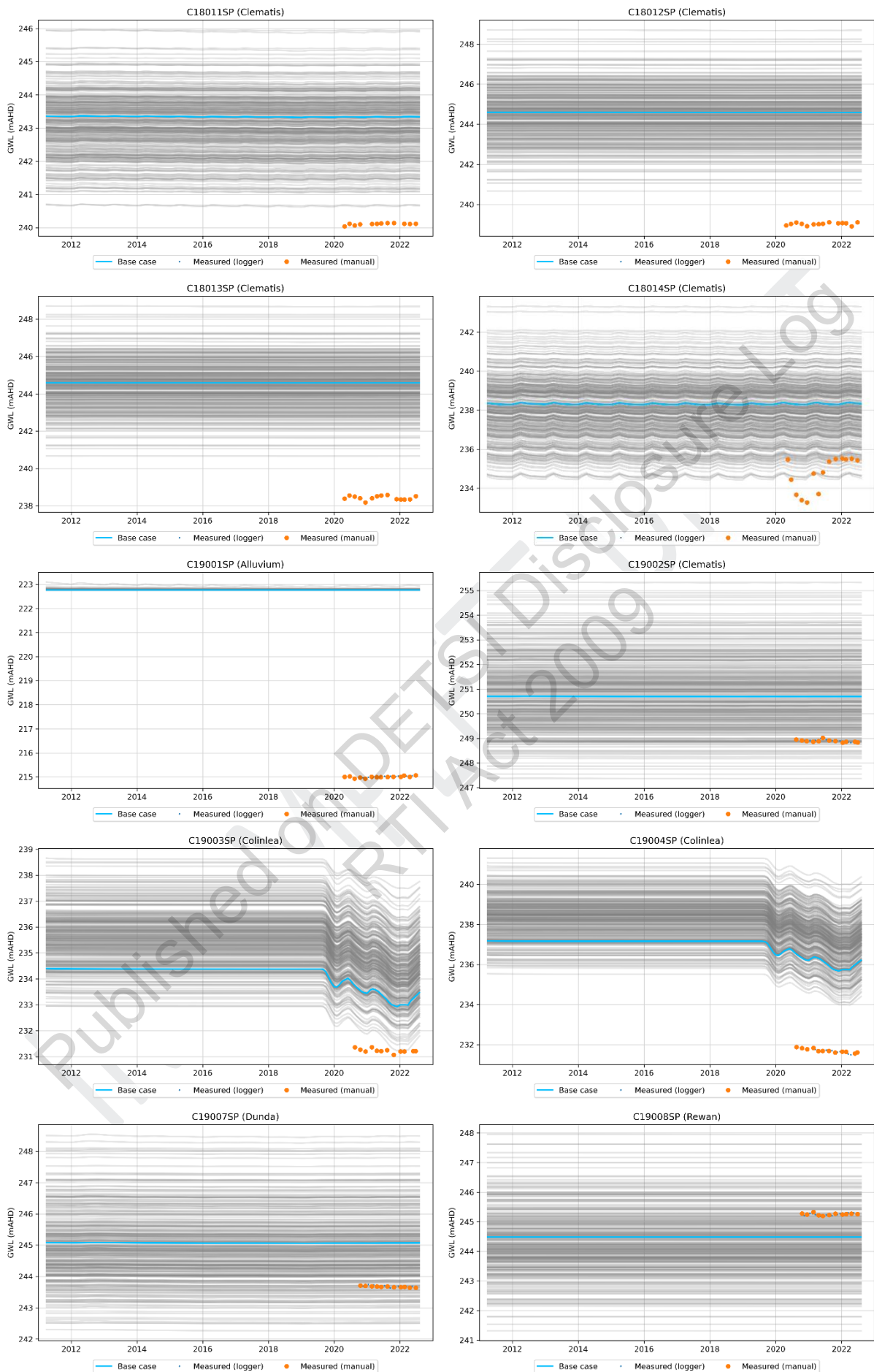


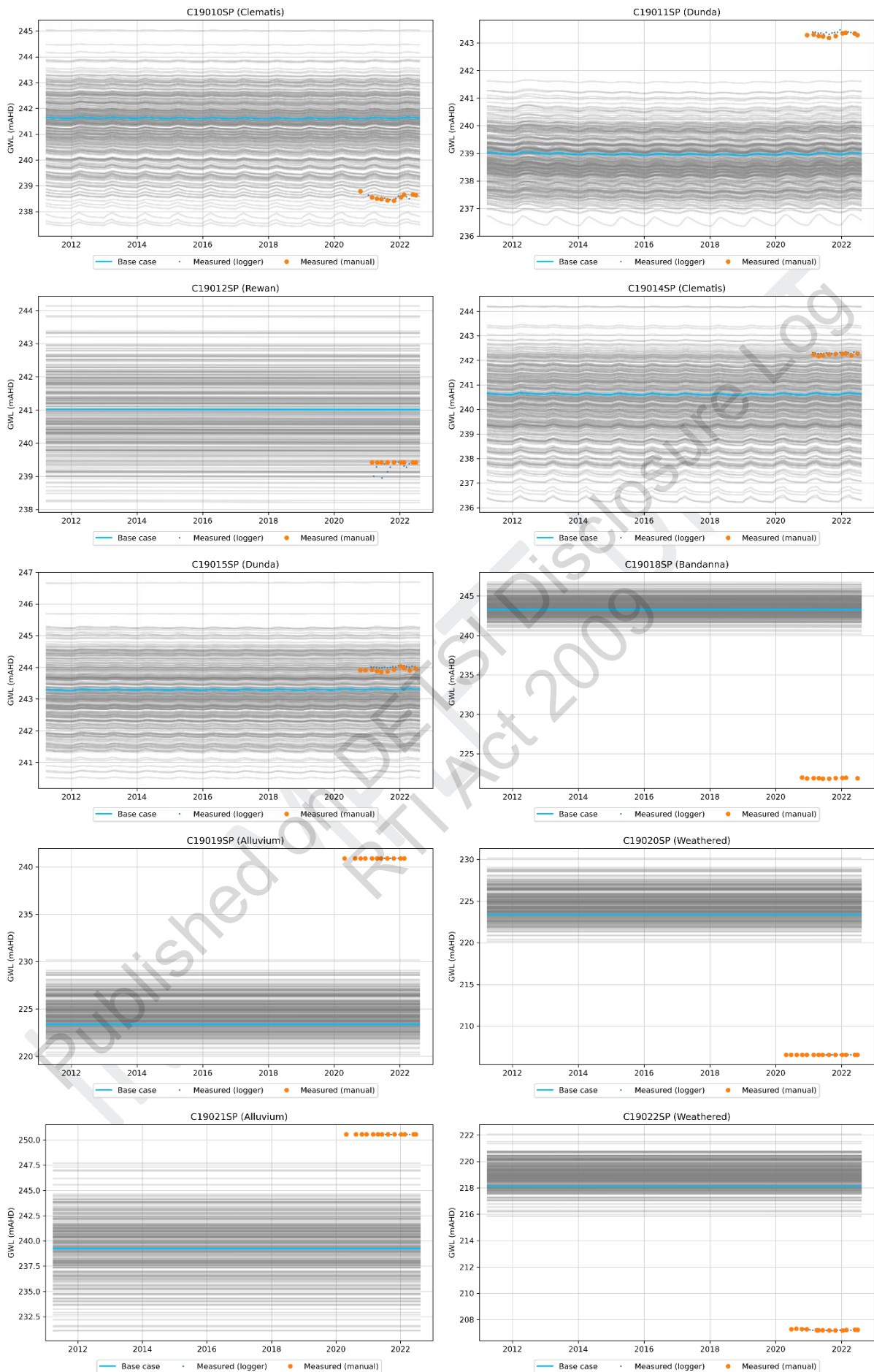




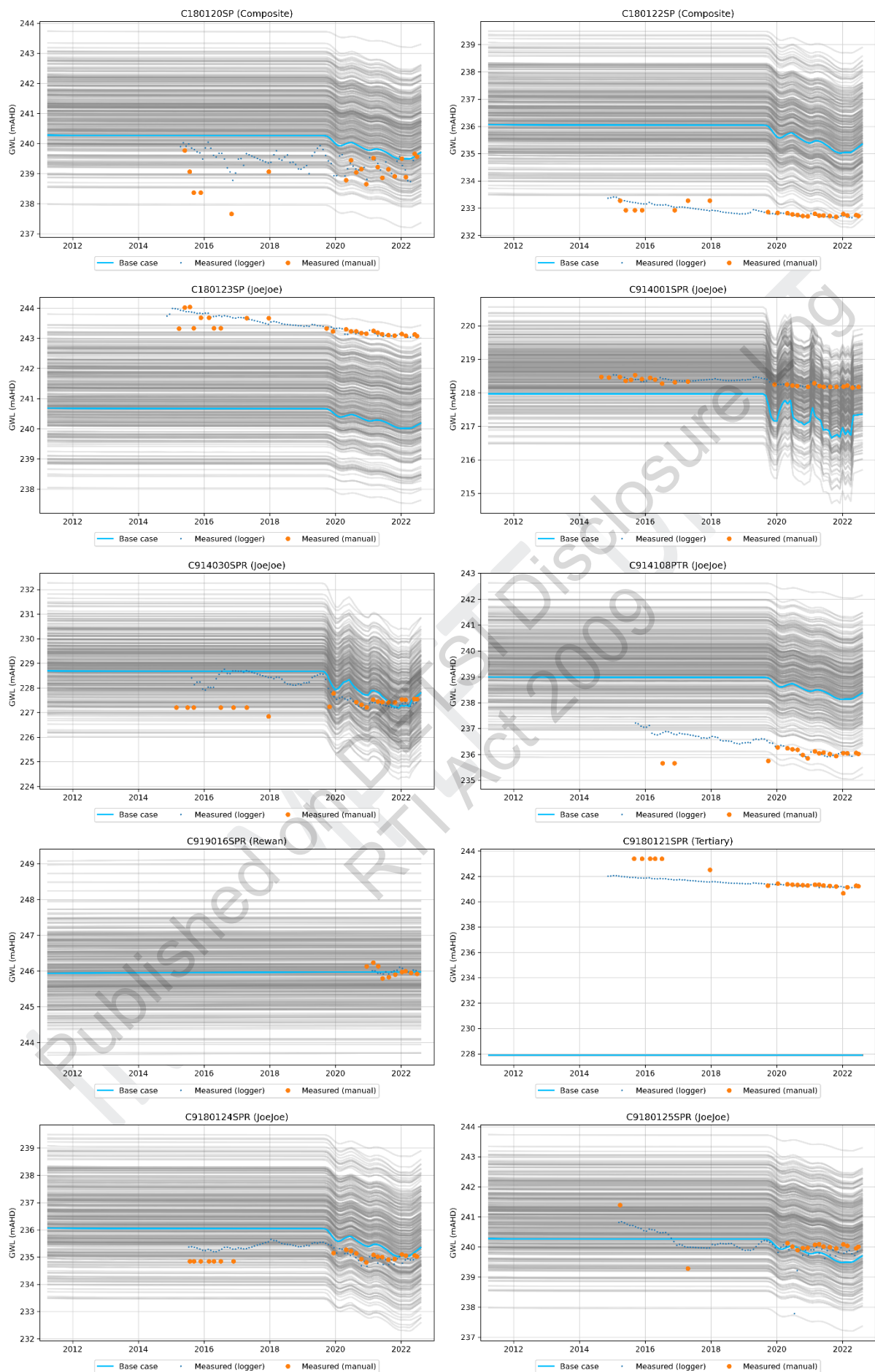


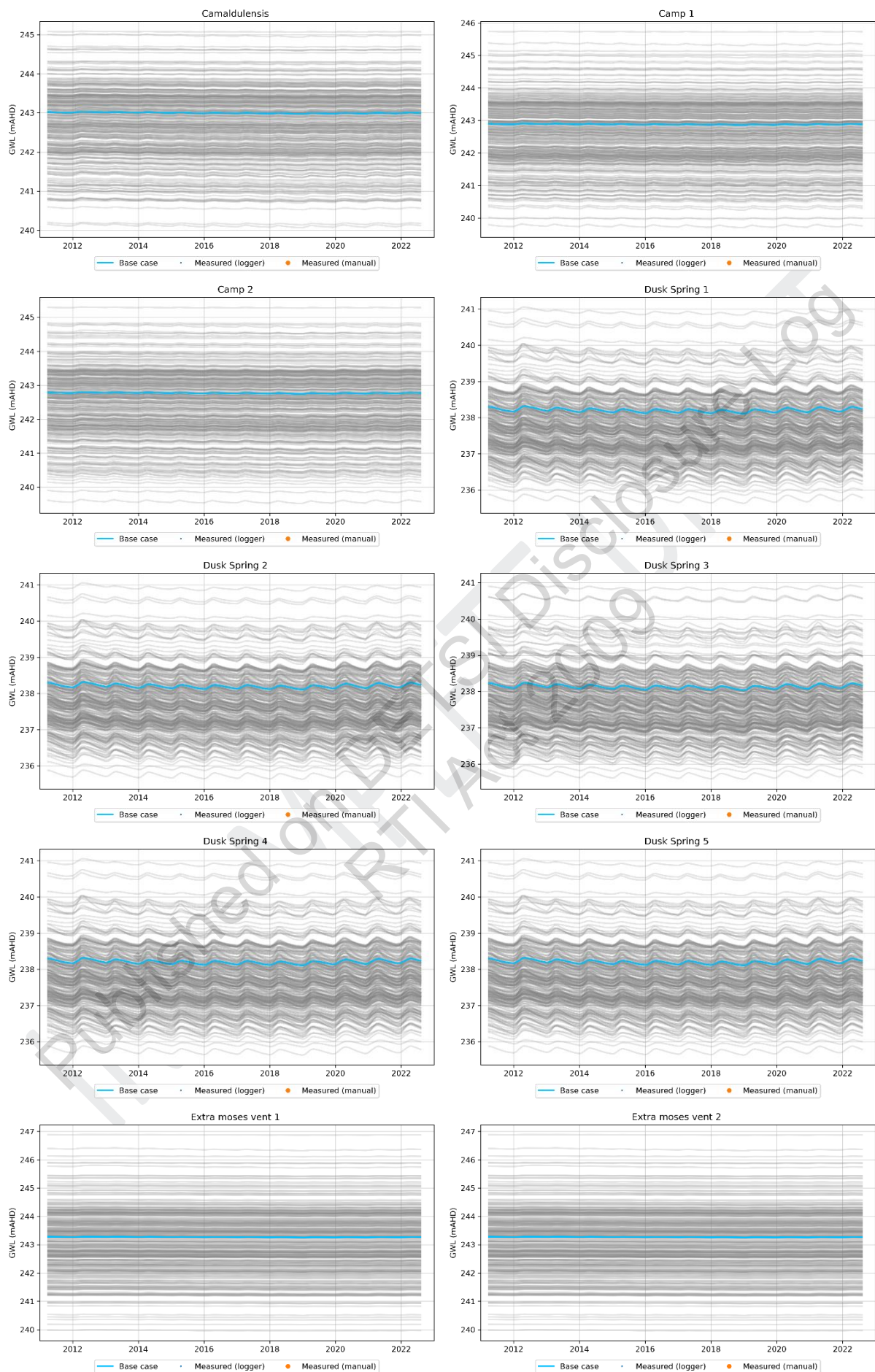


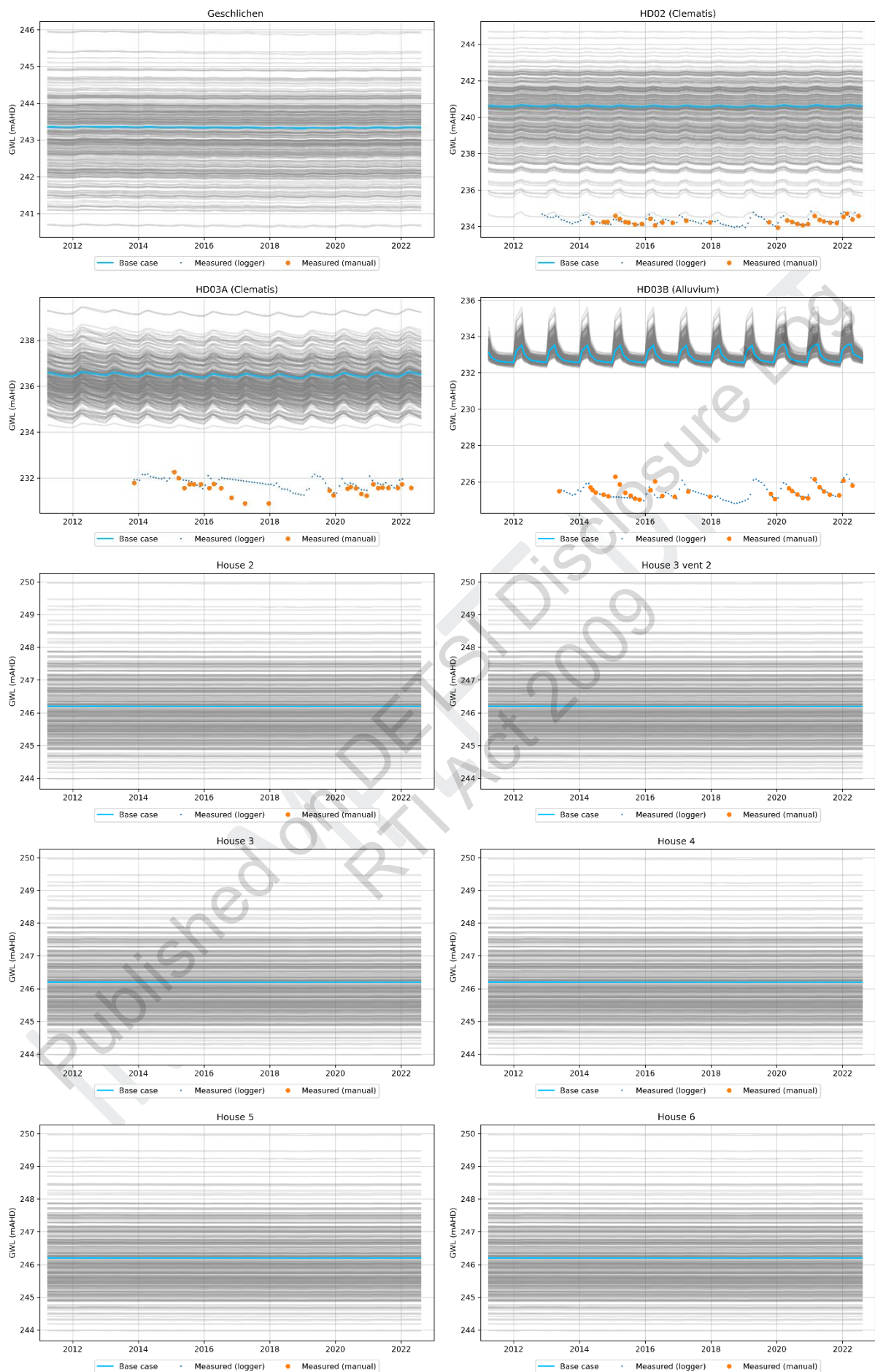


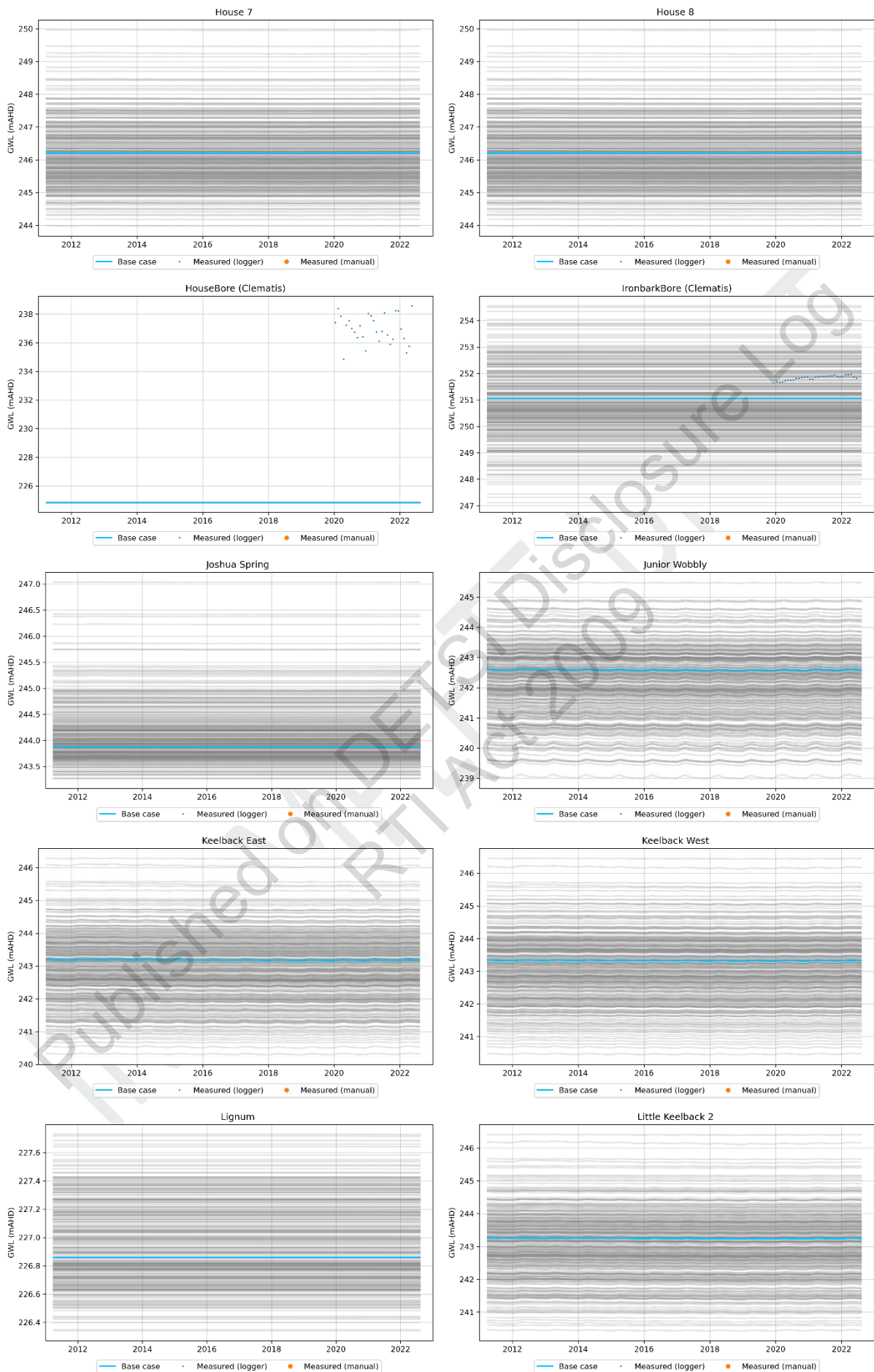


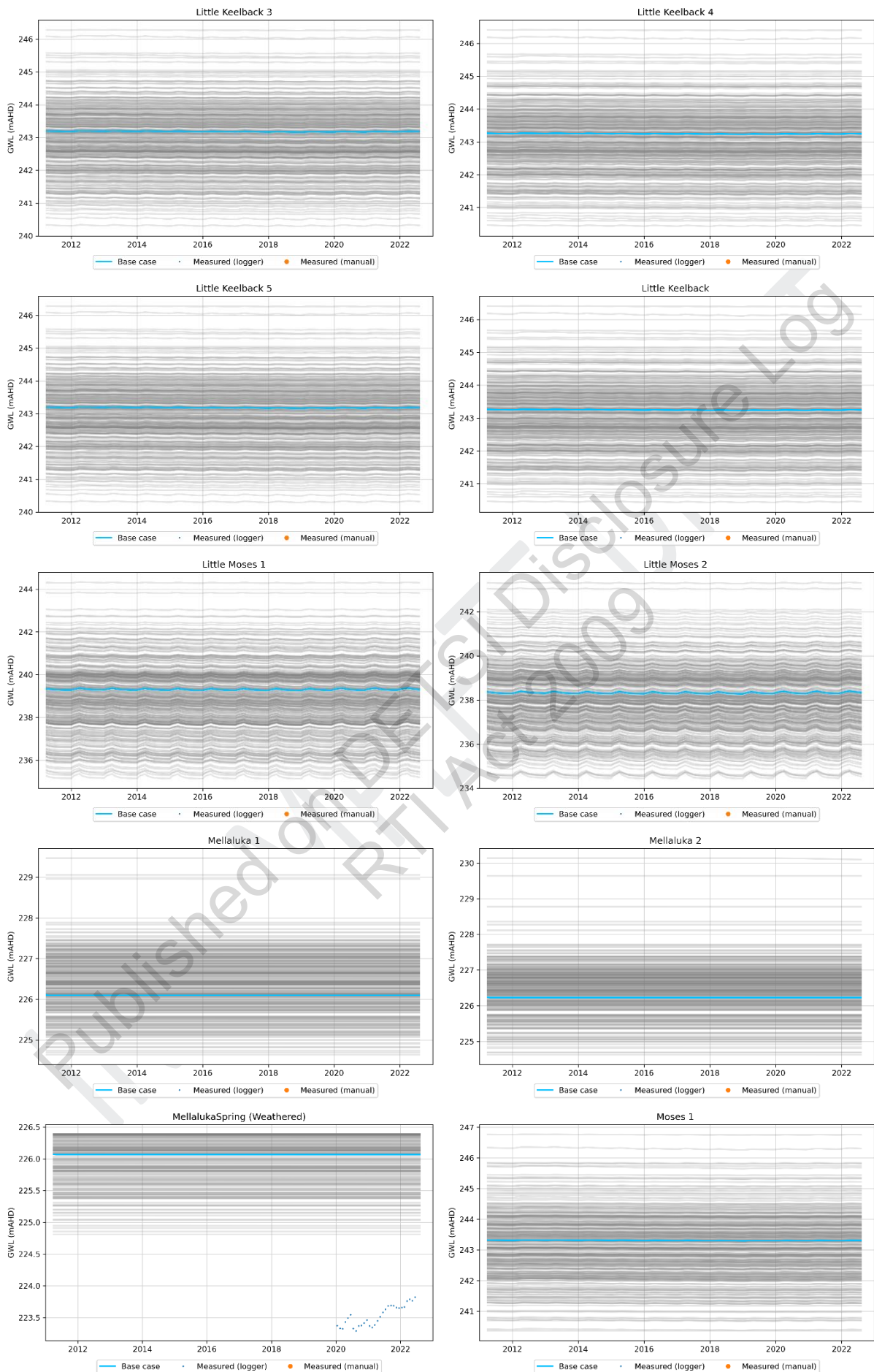


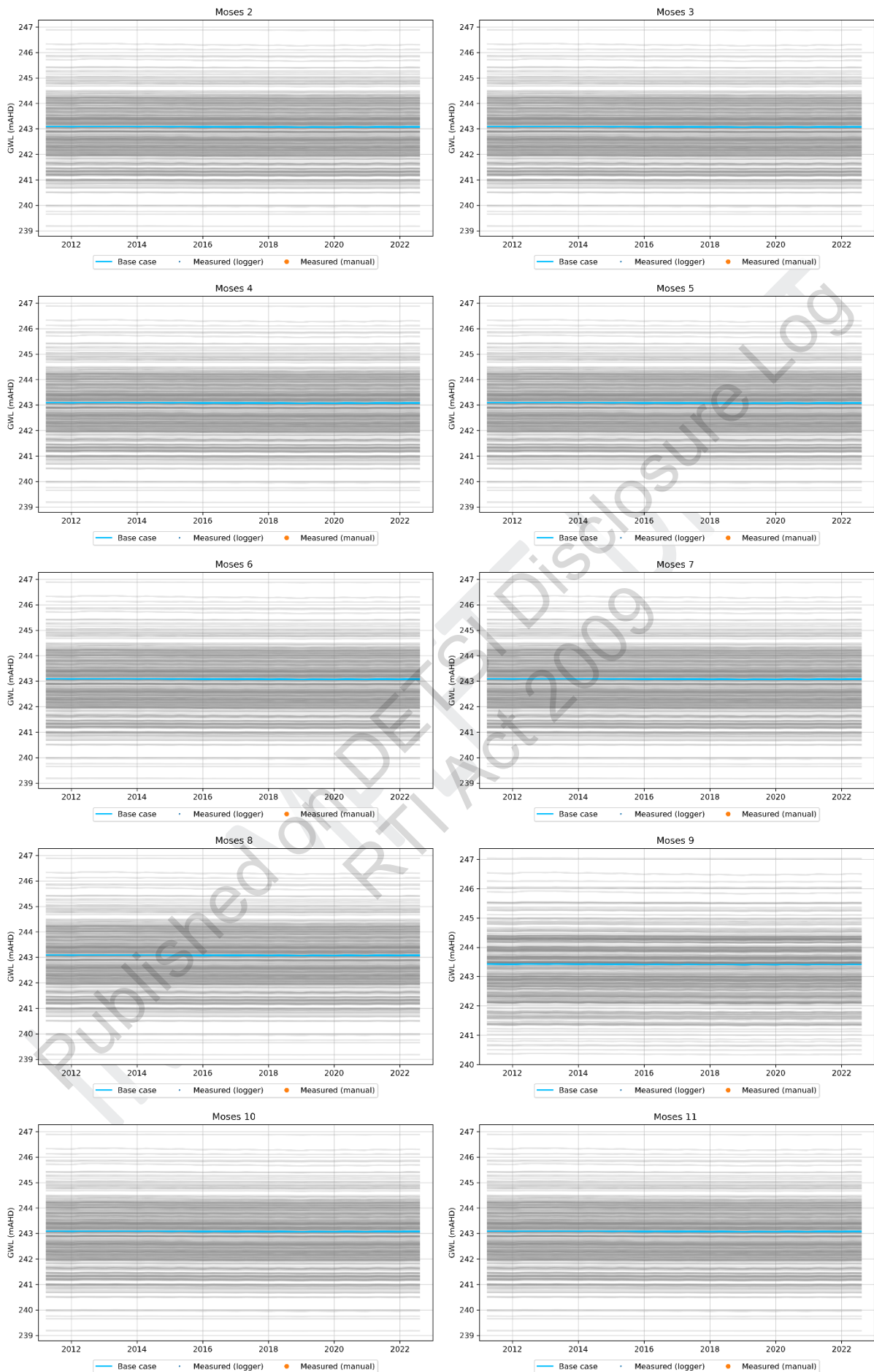


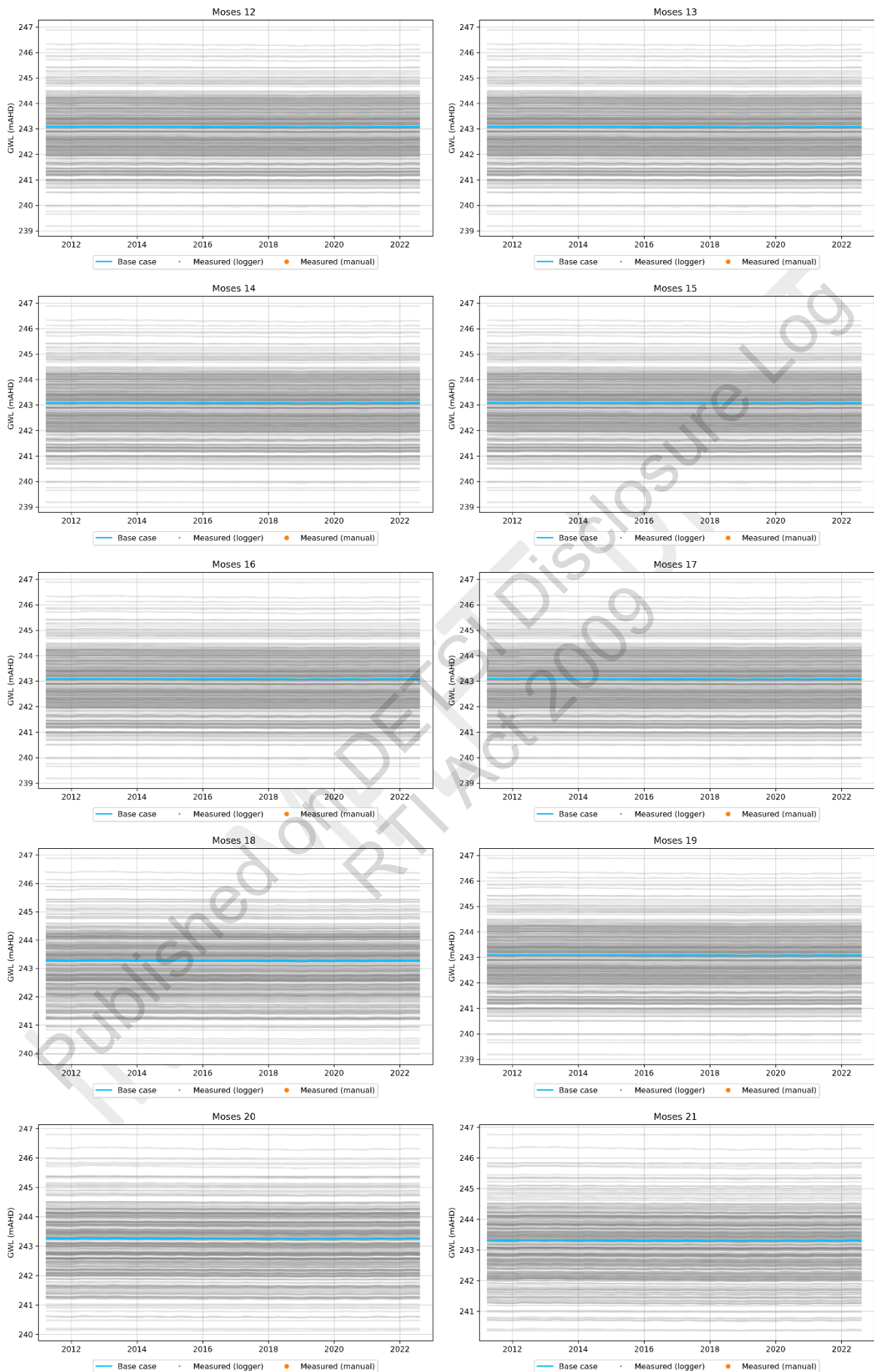


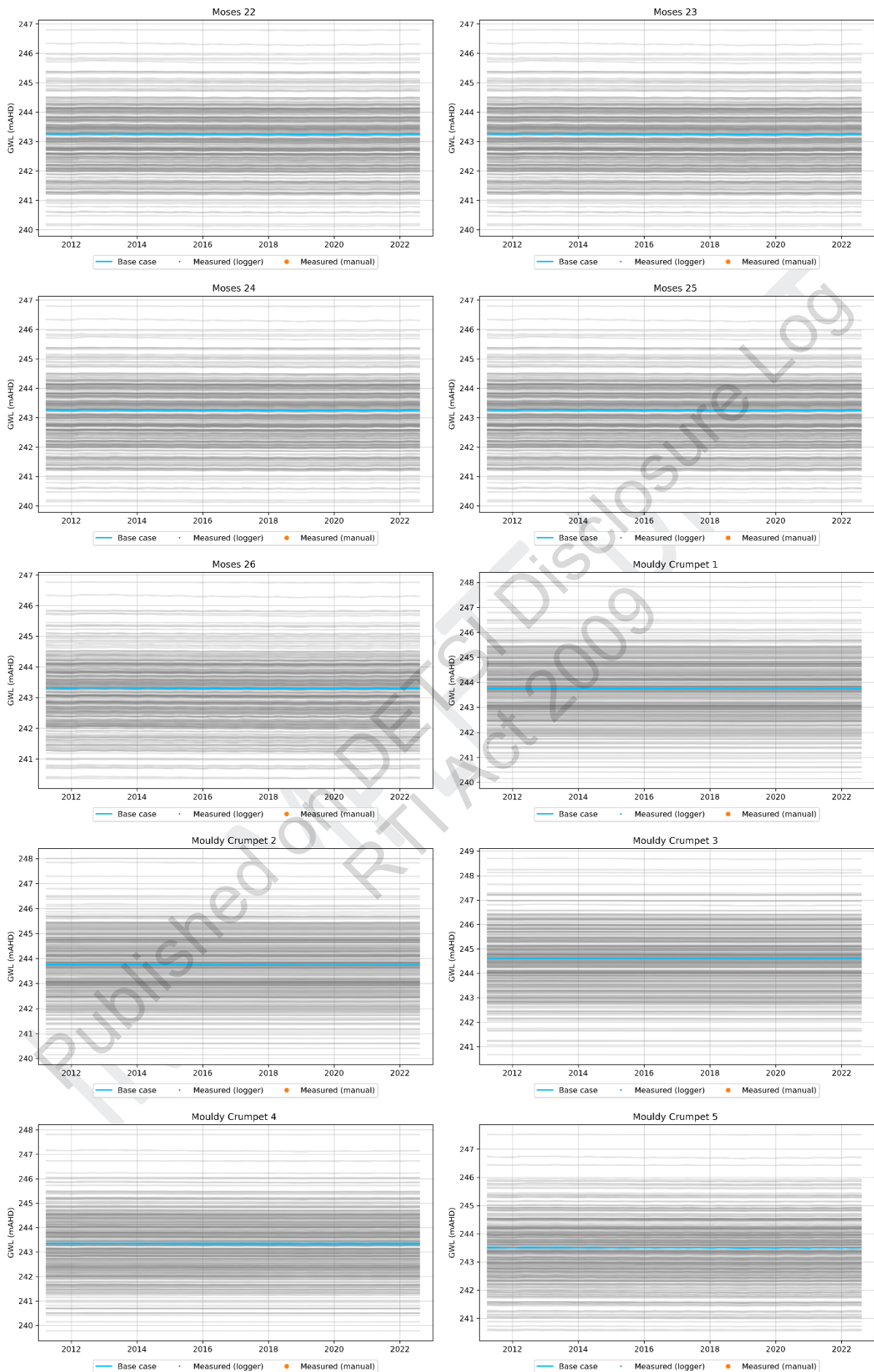


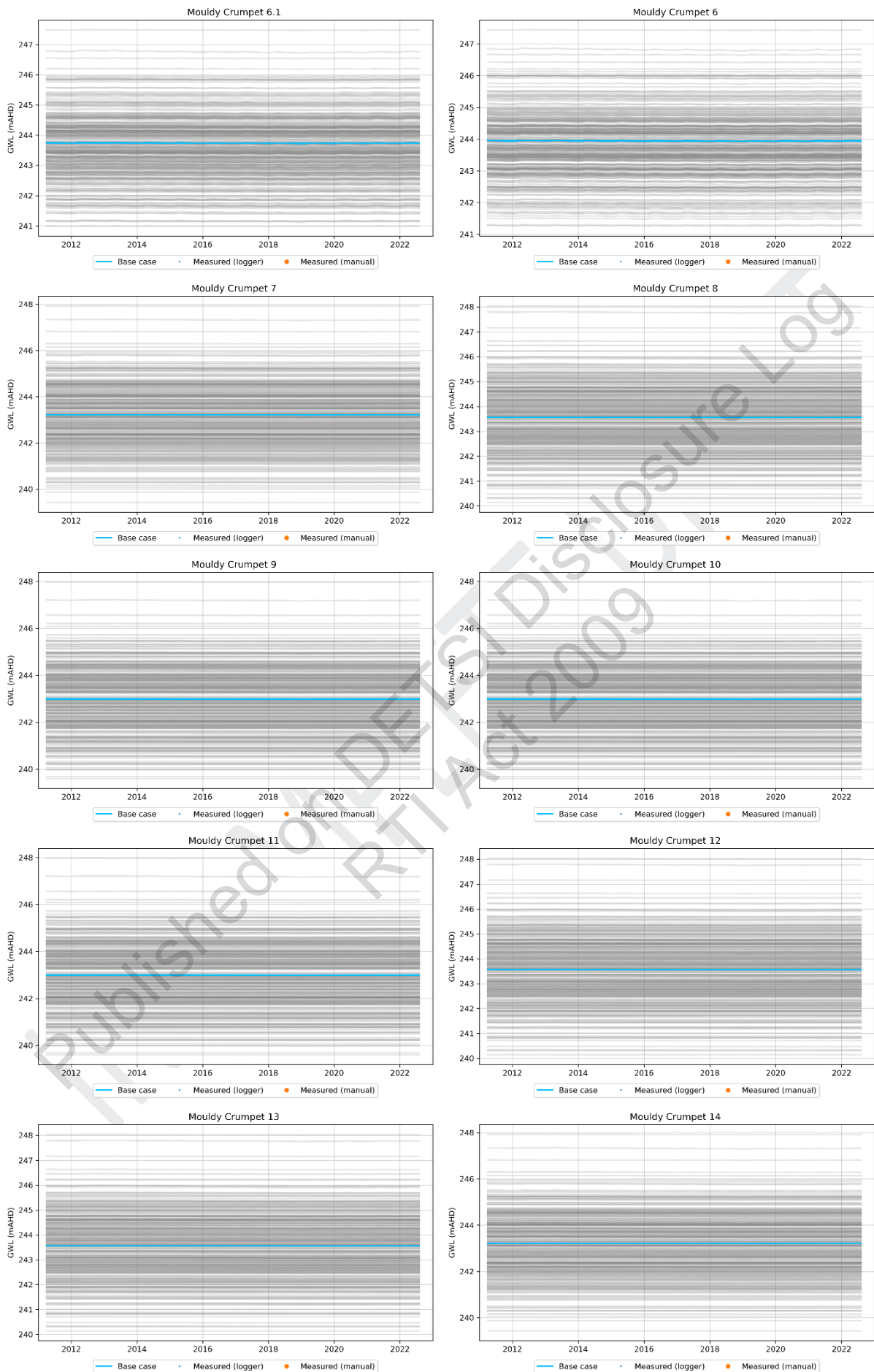


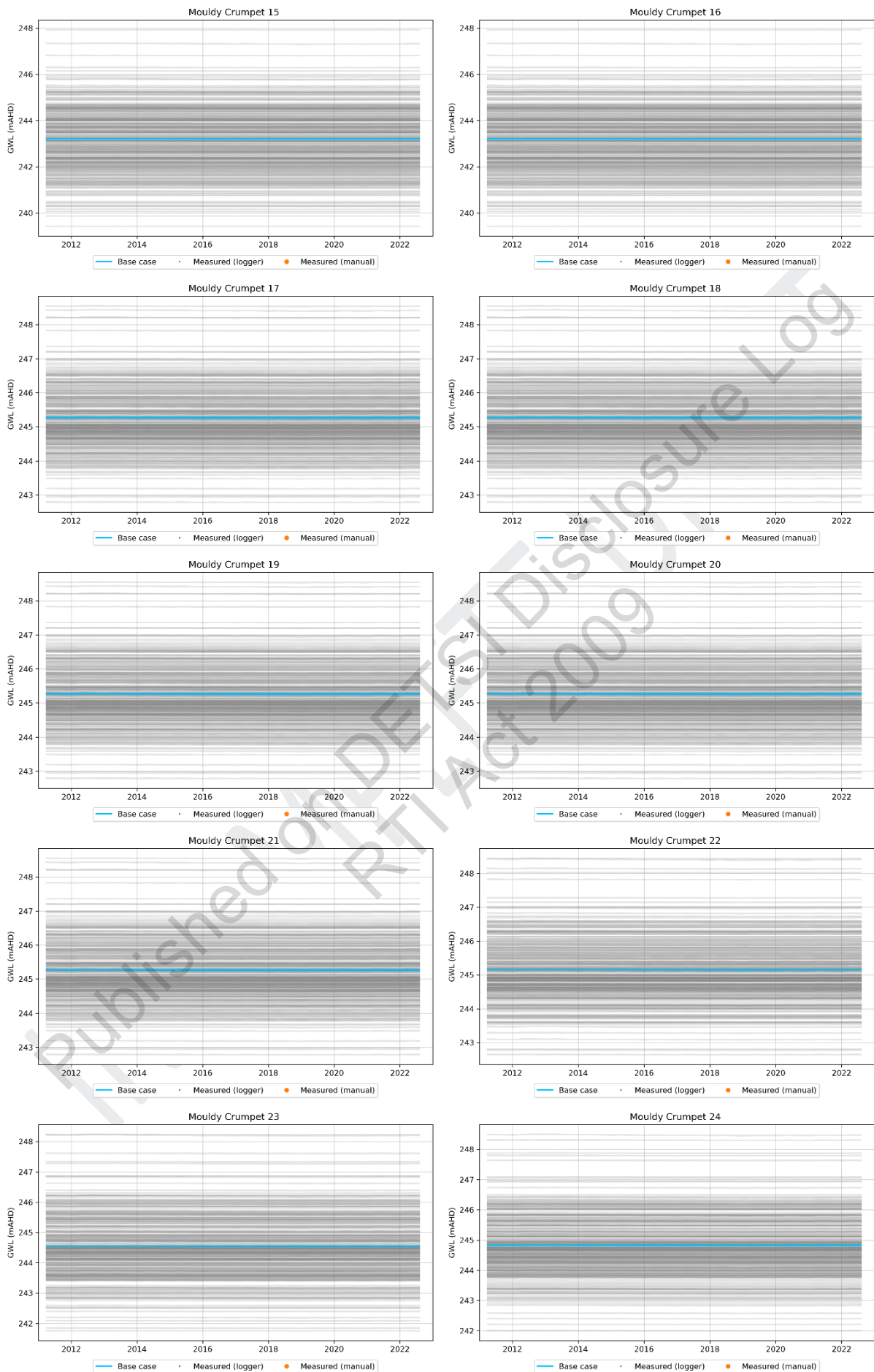


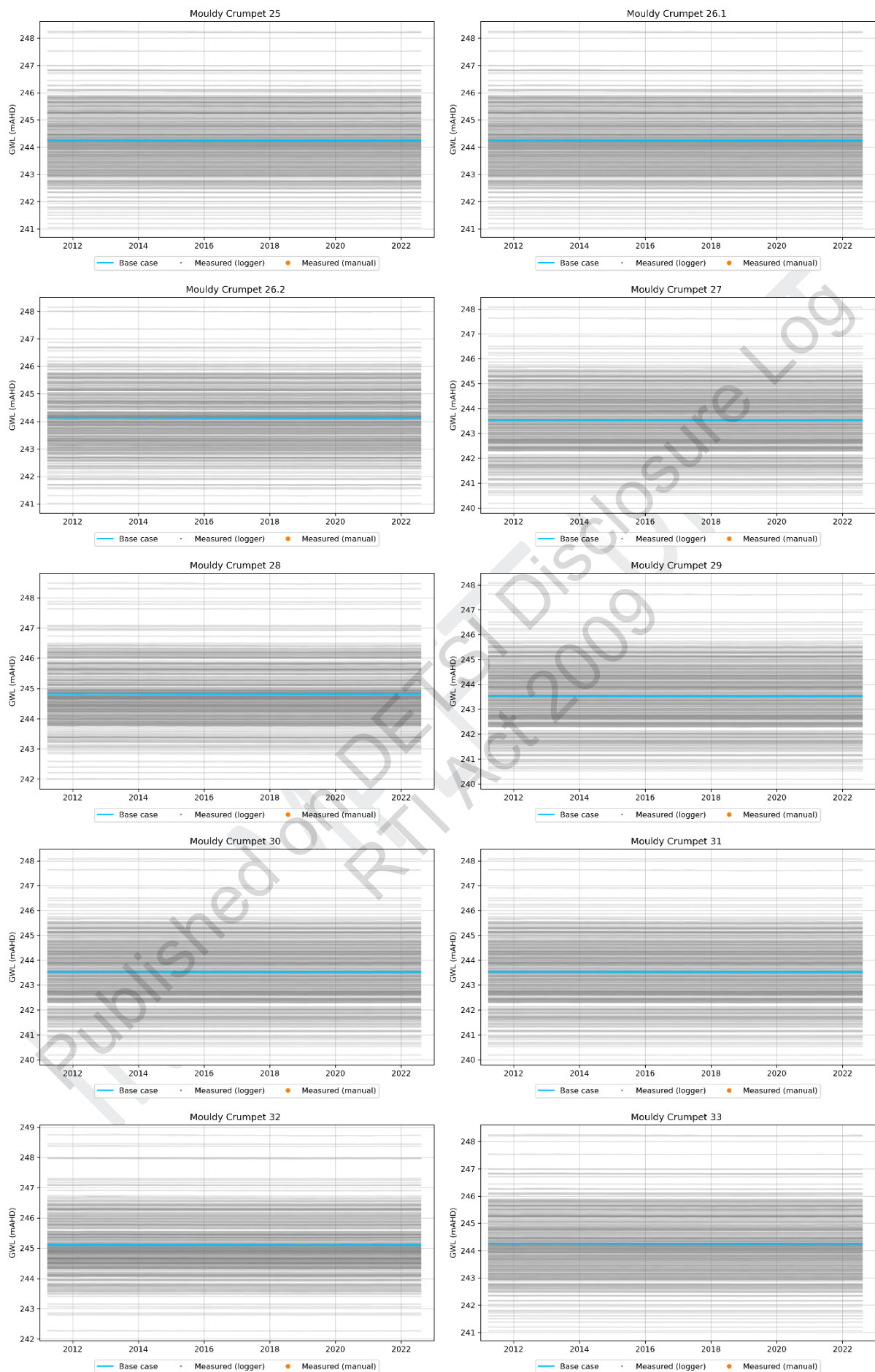


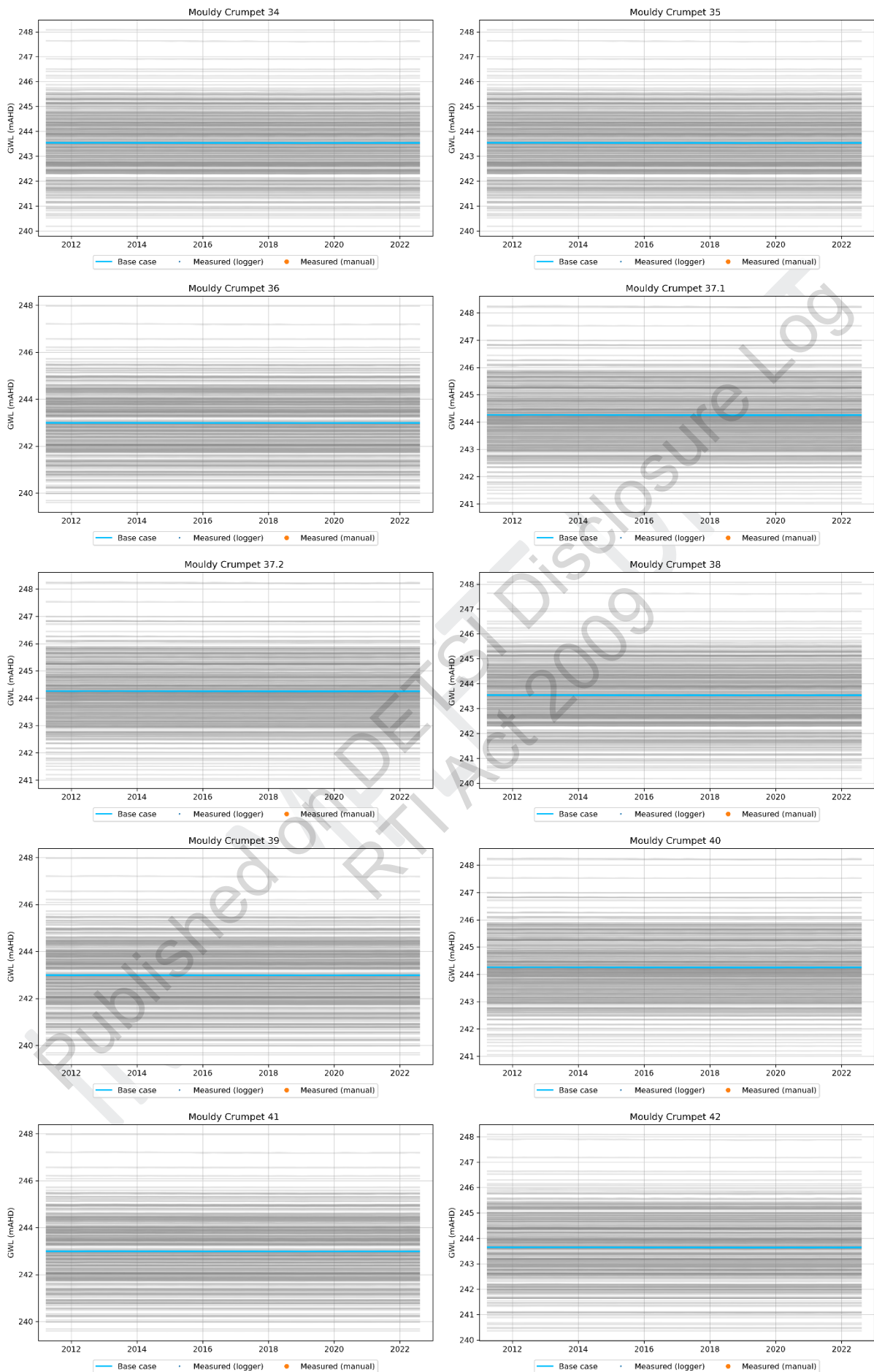


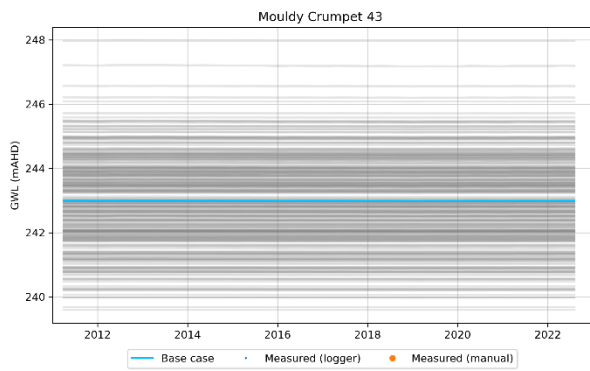
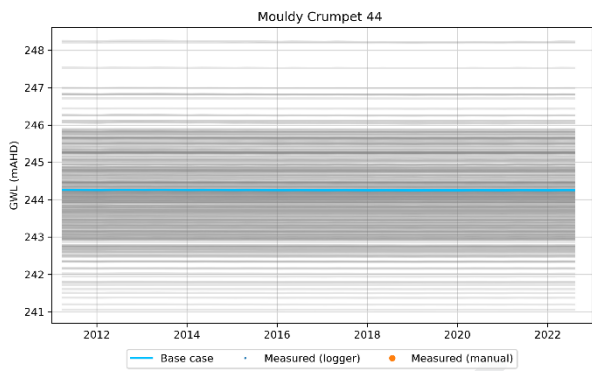
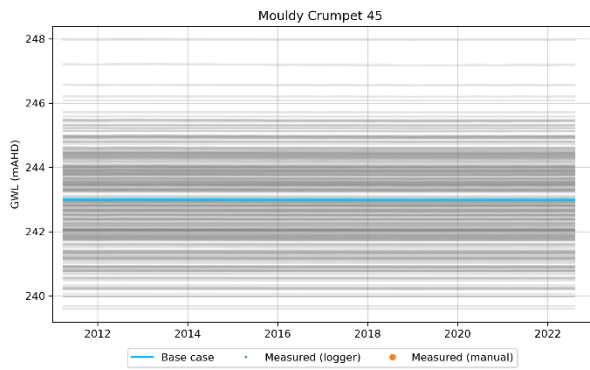
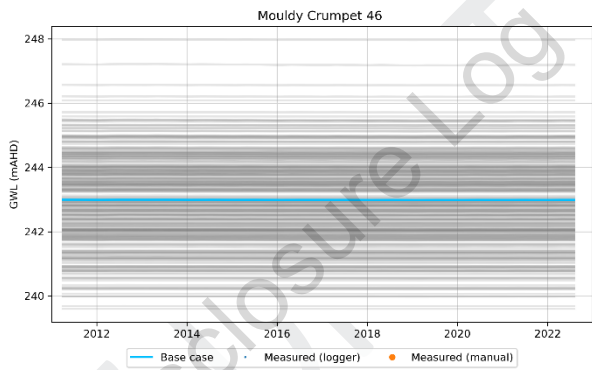
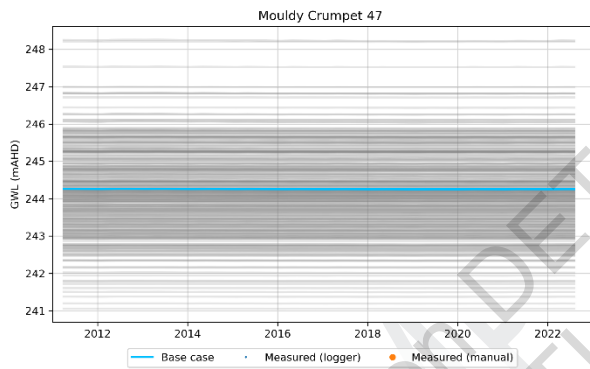
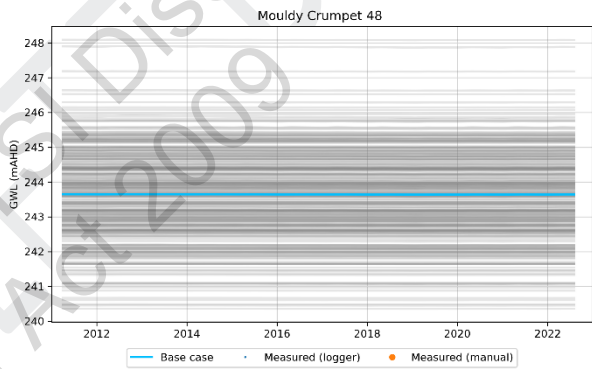
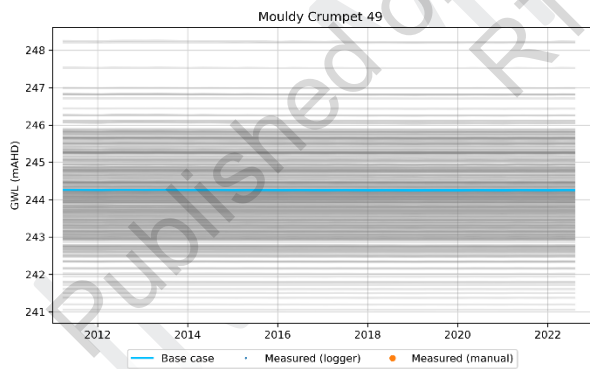
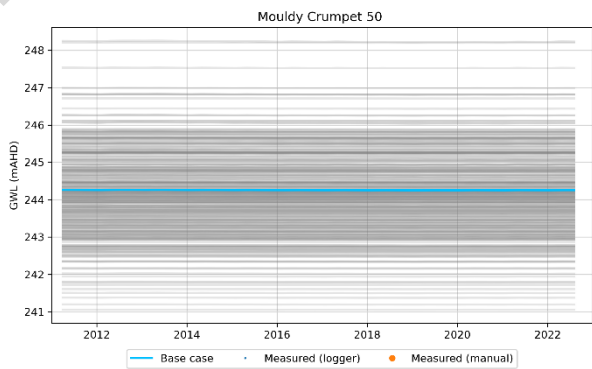
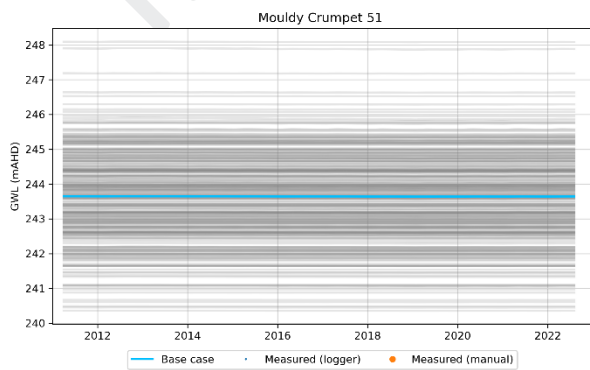
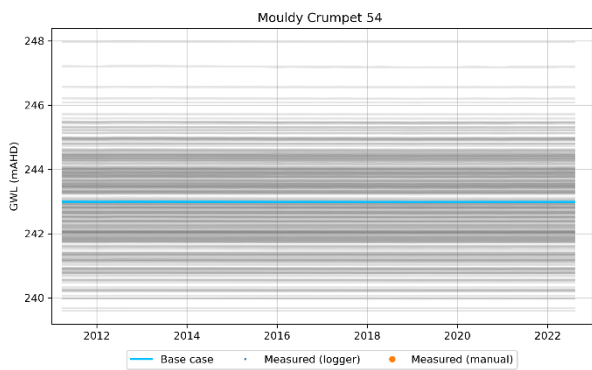


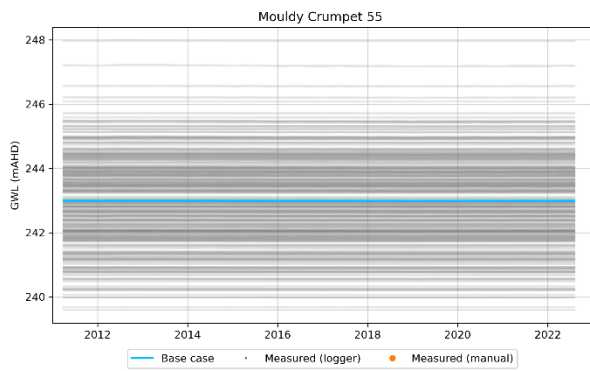
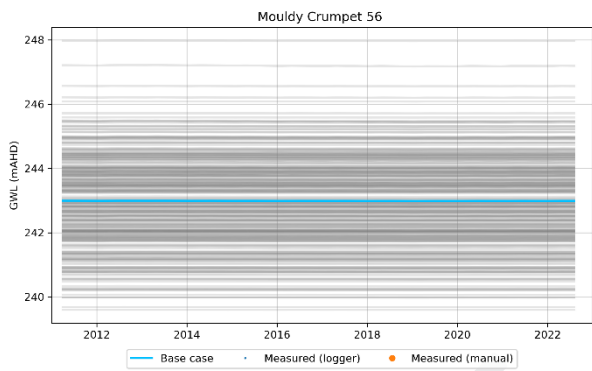
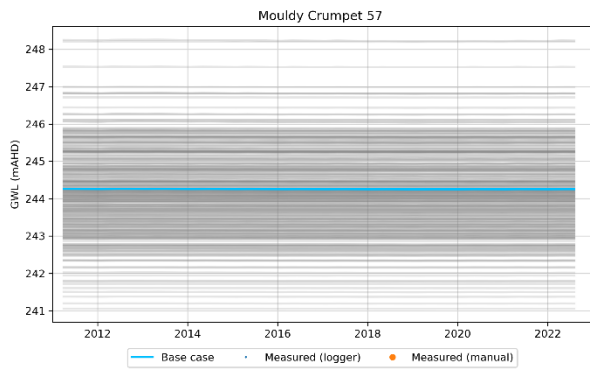
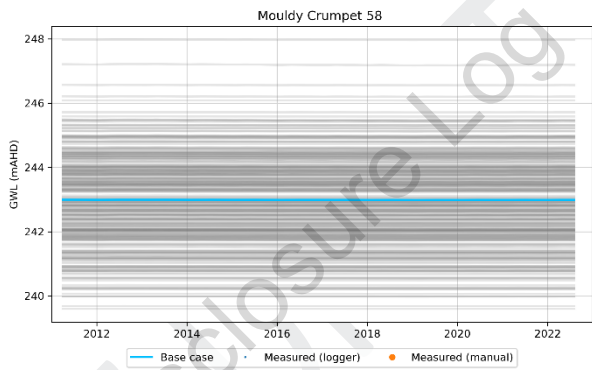
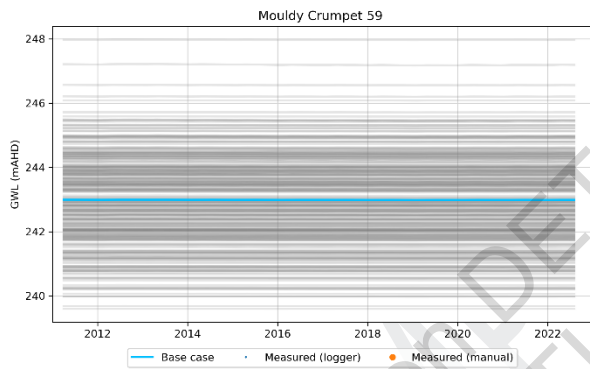
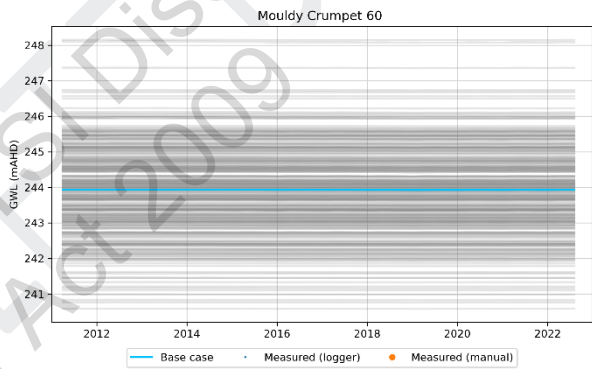
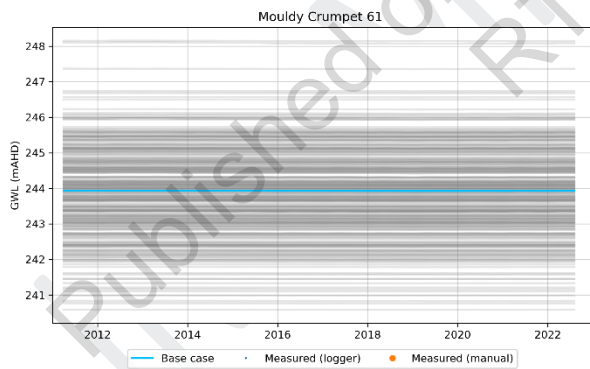
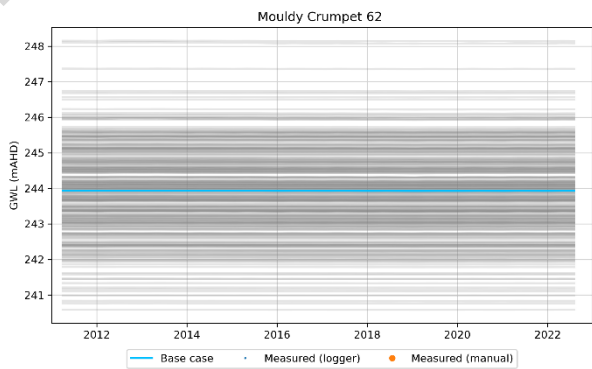
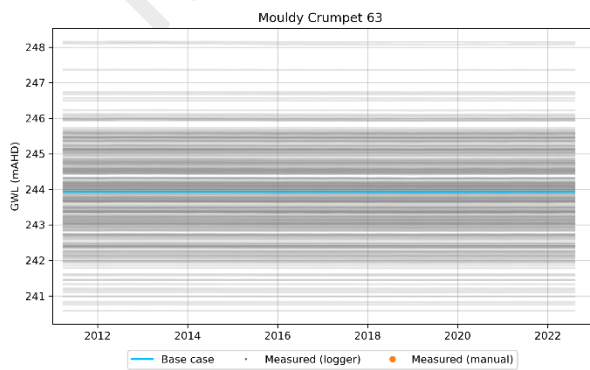
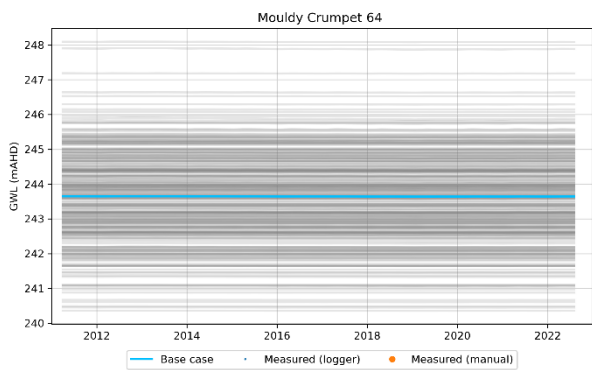


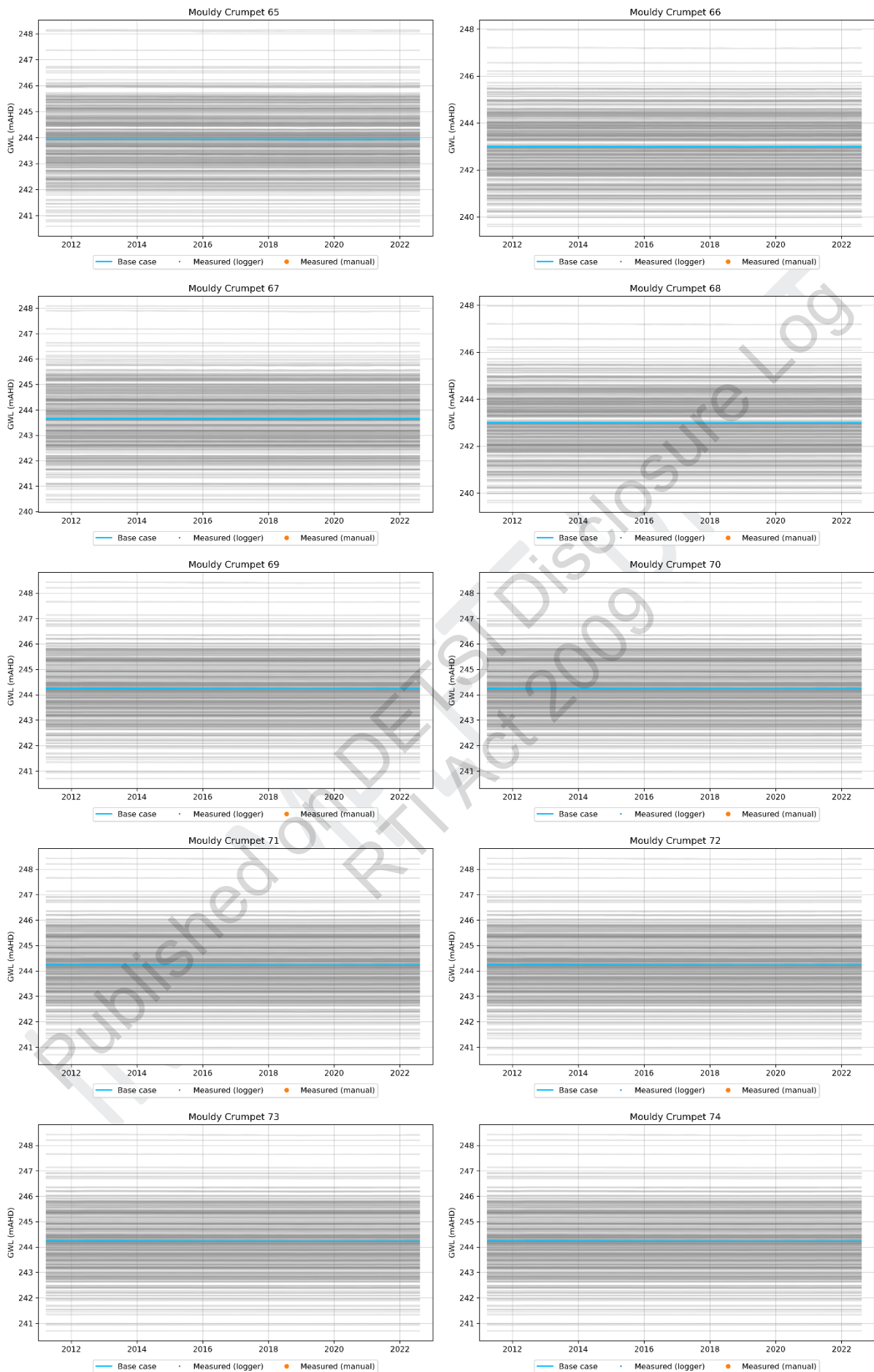


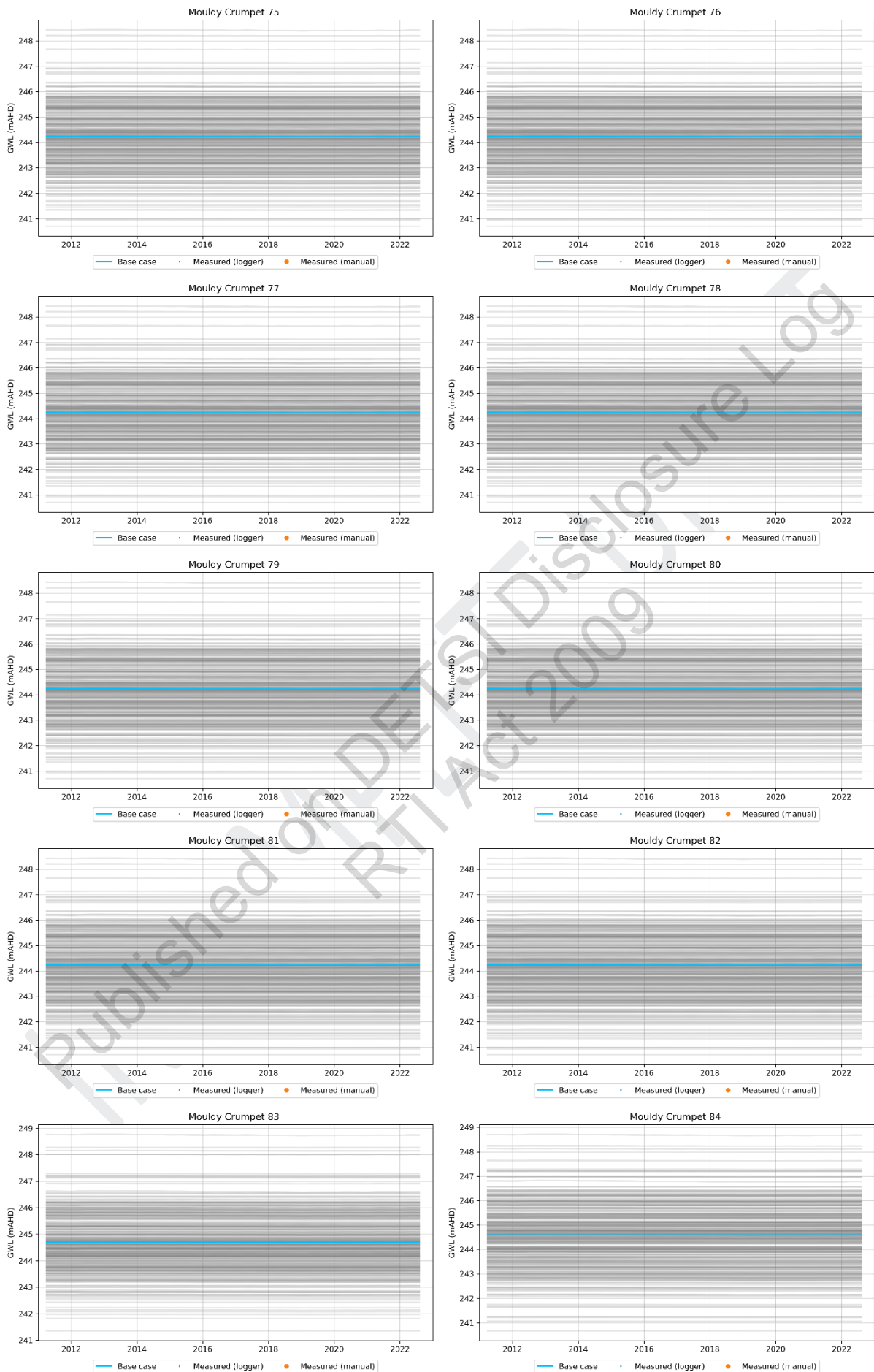


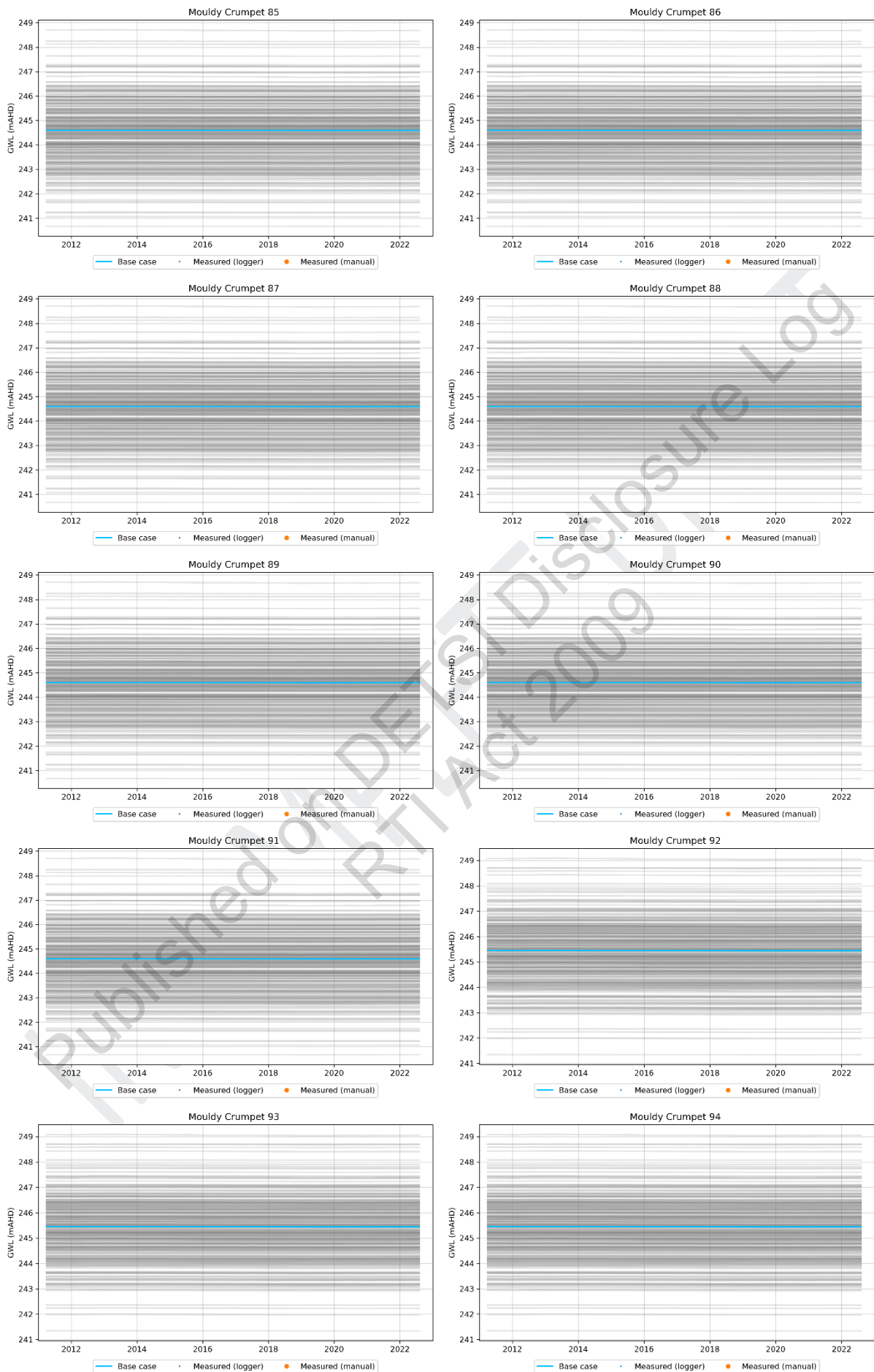


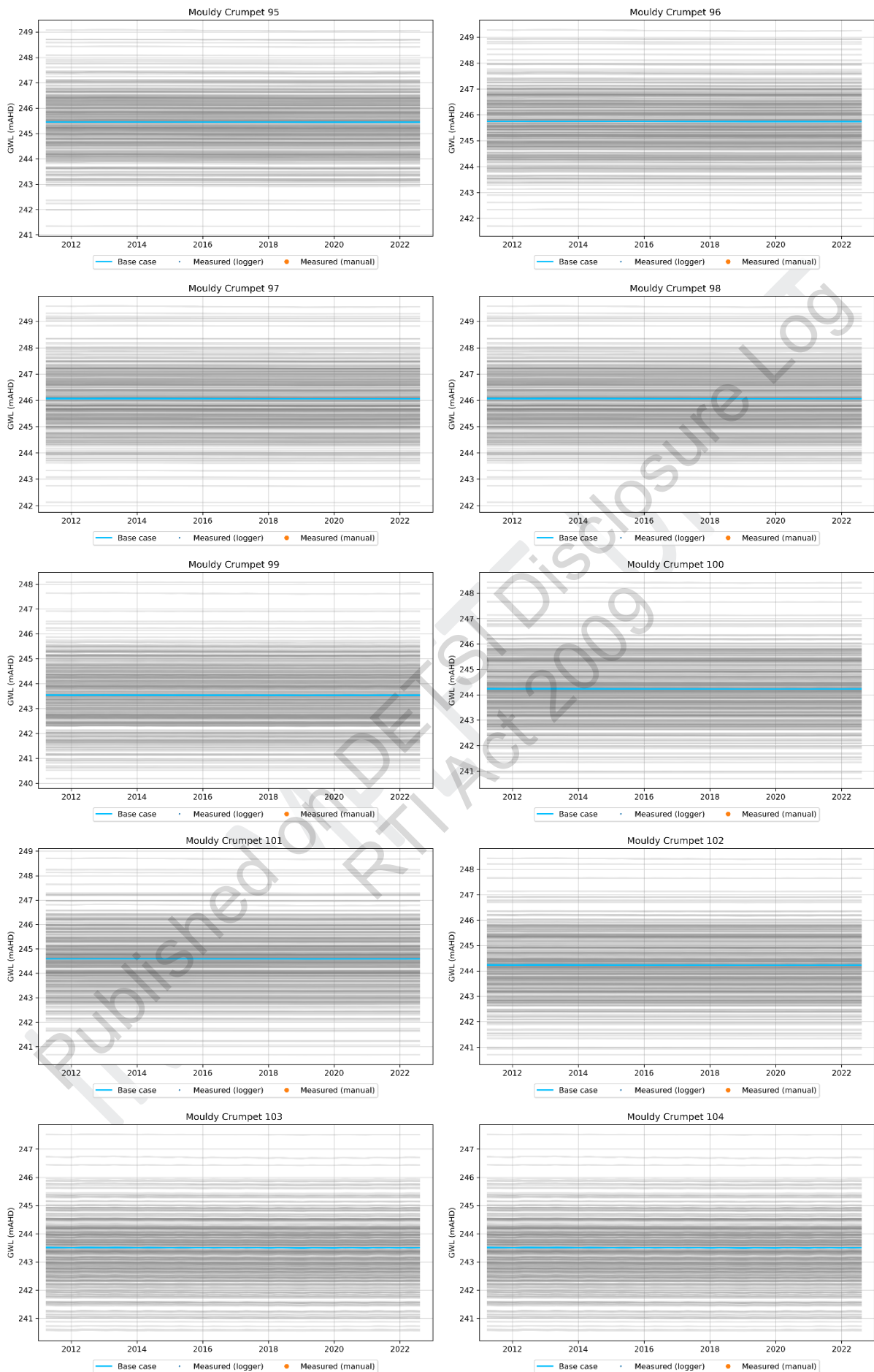


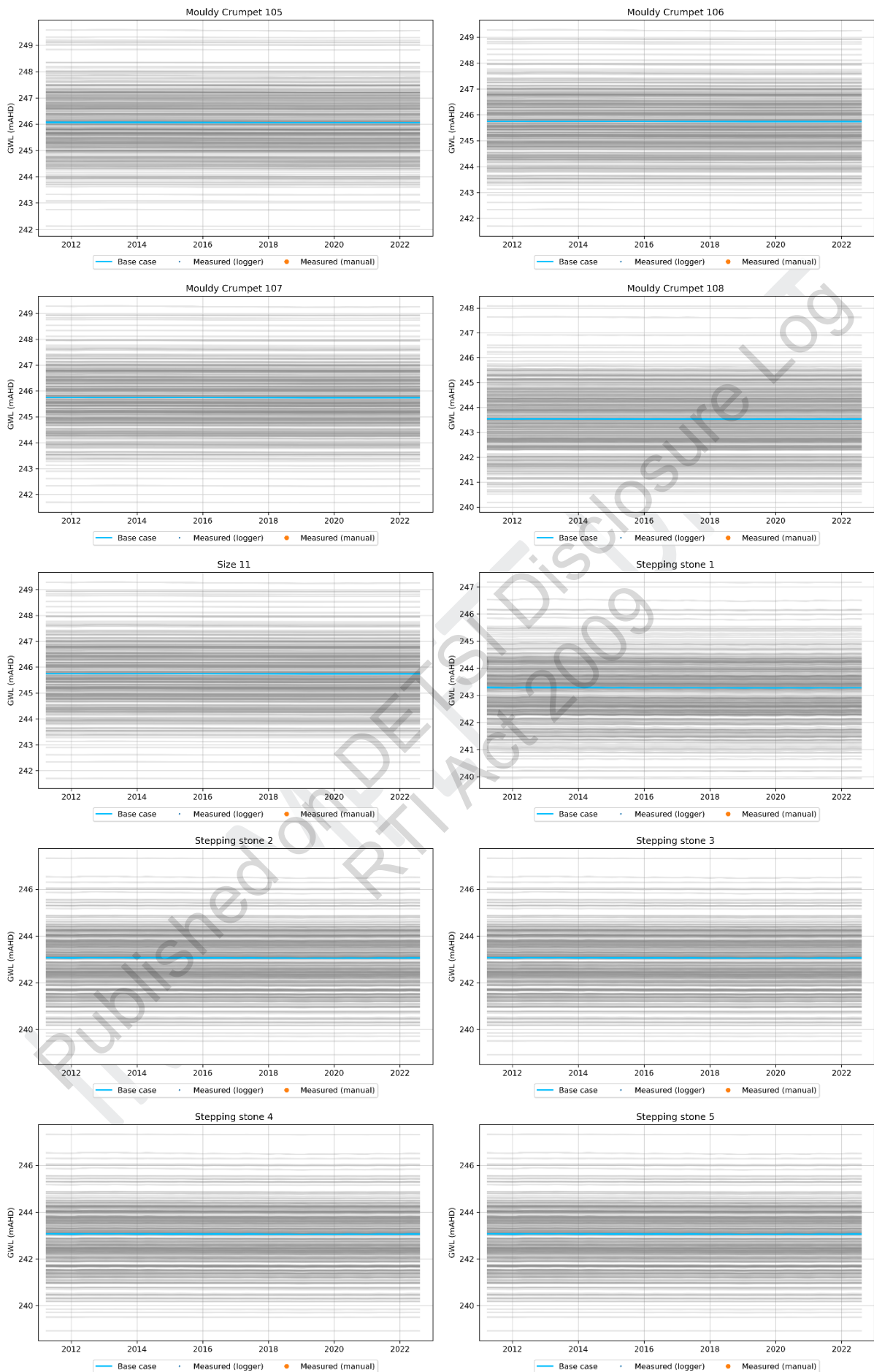


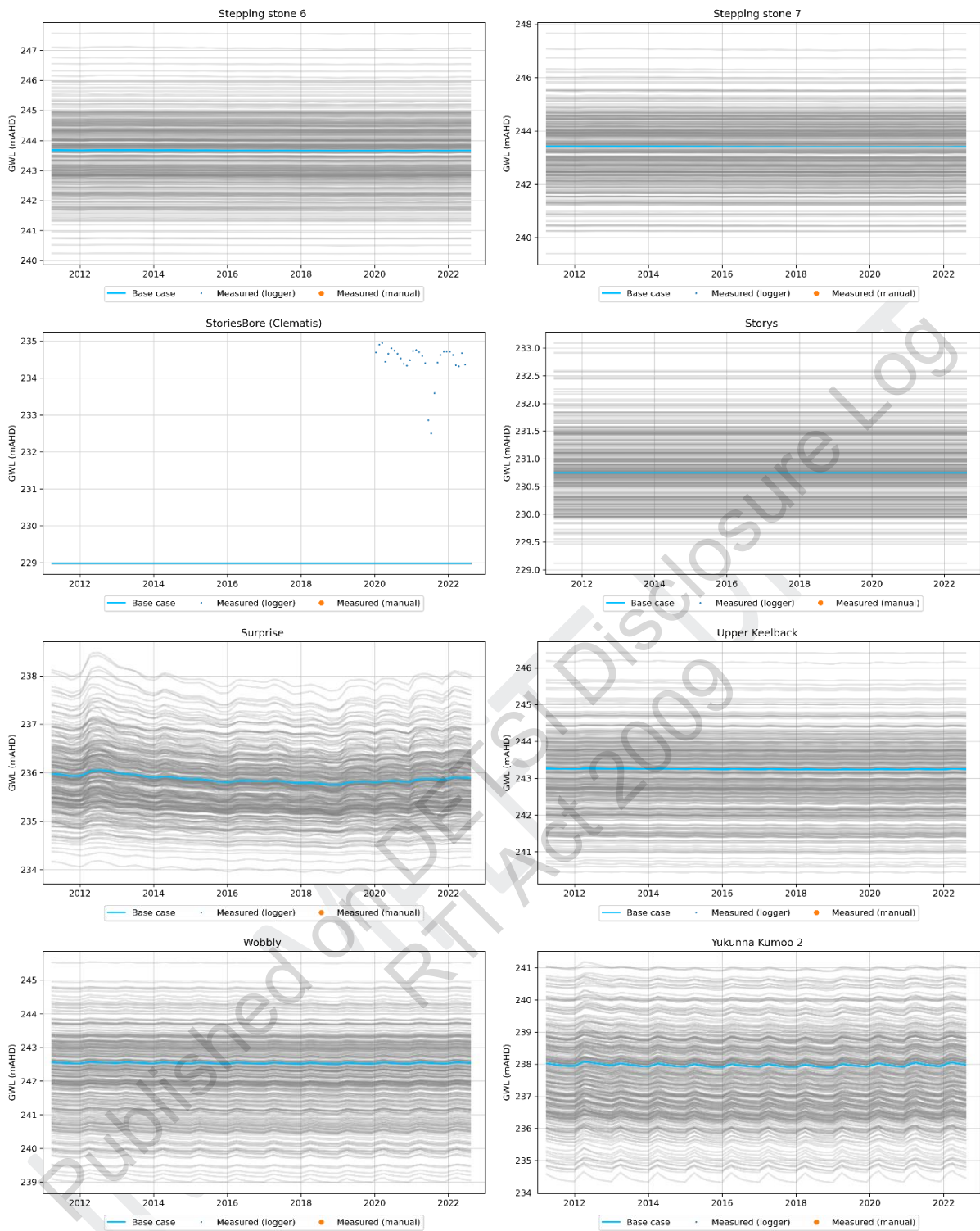


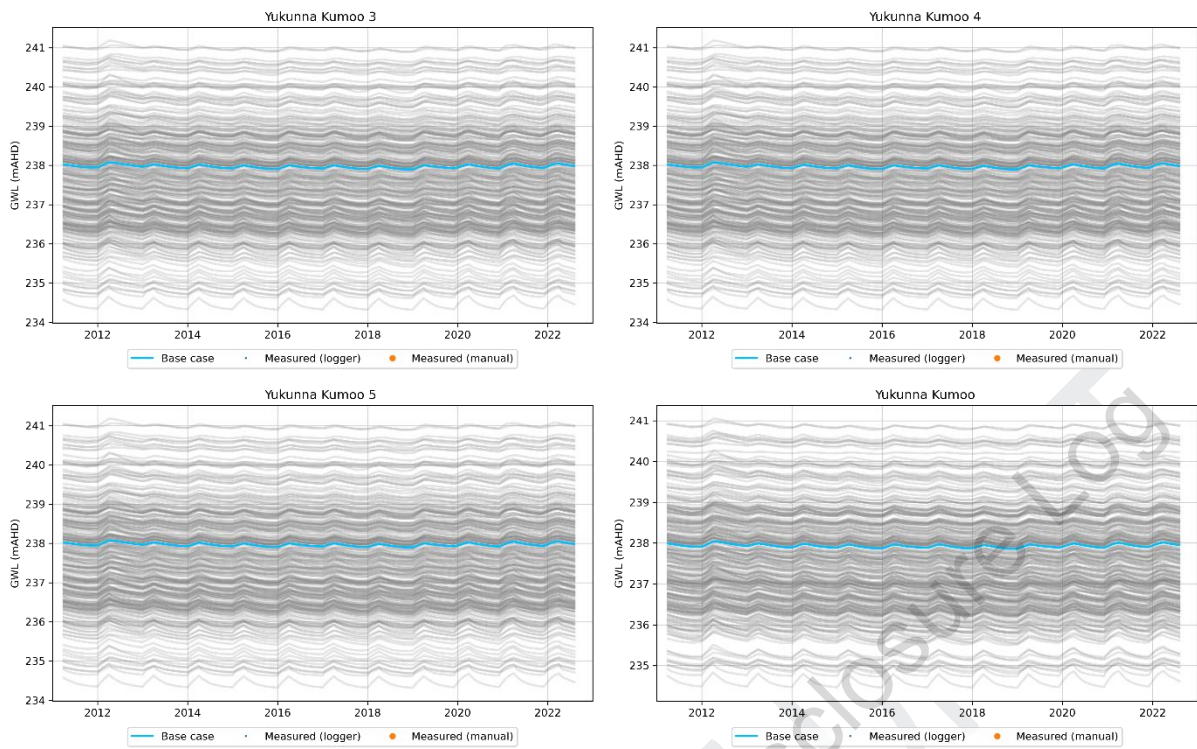












Appendix D

Hydrographs: mining

D.1 Appendix Heading

Text here

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Appendix E

Hydrographs: mining and recovery

E.1 Appendix Heading

Text here

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Appendix F

Hydrographs: predictive uncertainty drawdown

F.1 Appendix Heading

Text here

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Preliminary review of the Carmichael Coal Mine groundwater model report

Initial Heads

Bandanna Formation, Colinlea Sandstone and Joe Joe Formation

There is an area on the northern side of the Carmichael River encompassing the area of current mining, where in the pre mining period the lowest groundwater levels in the Bandanna Formation and Colinlea Sandstone have been noted as have some in the Joe Joe Formation.

In this current report Table 2.1 – Summary of the Conceptual Hydrogeological model, states:

- *A synform had been proposed during the SEIS phase, with a northeast to southwest fold axis that passes broadly through the centre of the site. The synform affects the Betts Creek Beds and Rewan Formation and the fold axis tends to align with a regional potentiometric 'low'.*
- *Two alternative conceptualisations have been recently proposed by EMM (EMM 2022a) as an alternative to the synform: local faulting or a permeable Joe Joe Group acting as an underdrain. The local fault (or higher permeable zone) is conceptualised to cut across the Bandanna, Colinlea and Joe Joe Group mainly within the lease area.*

The table also states, under the heading of local groundwater flow:

Colinlea Sandstone: Groundwater flow converges towards bore C006P3R and is likely influenced by the local faulting/high permeable zone previously proposed.

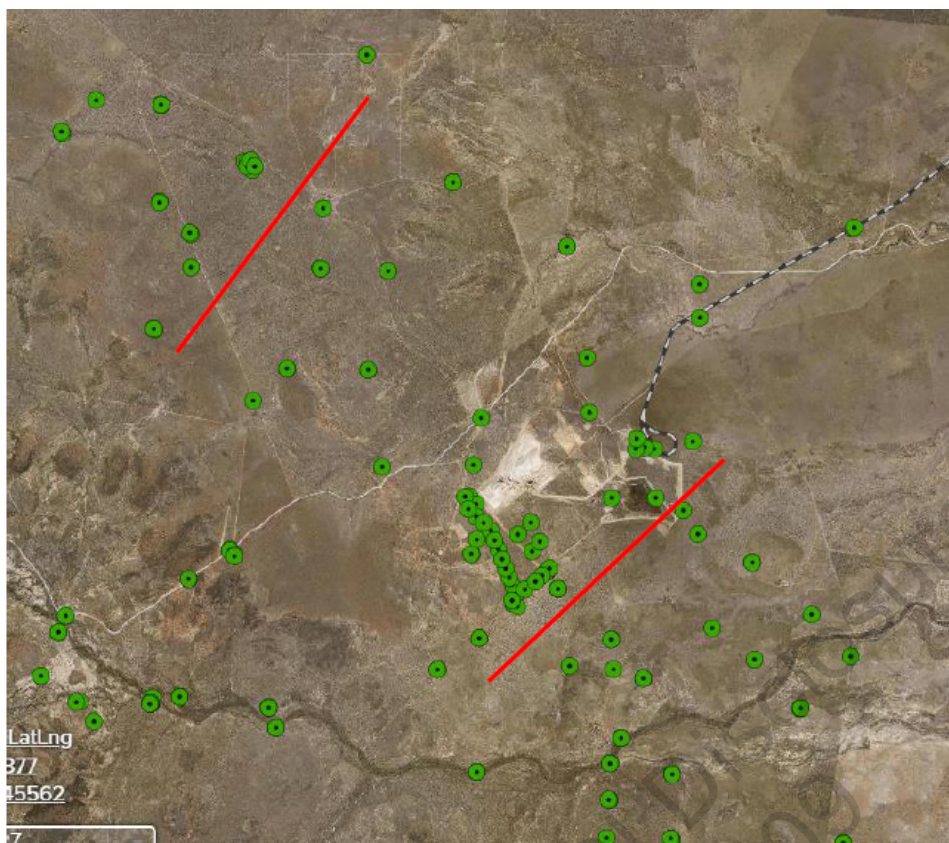
The synform theory is rejected as it does not account for the discharge of groundwater that would be required to cause these groundwater lows.

Whilst EMM have developed alternative conceptualisations they have not incorporated any of these potential discharge processes into the numerical groundwater model.

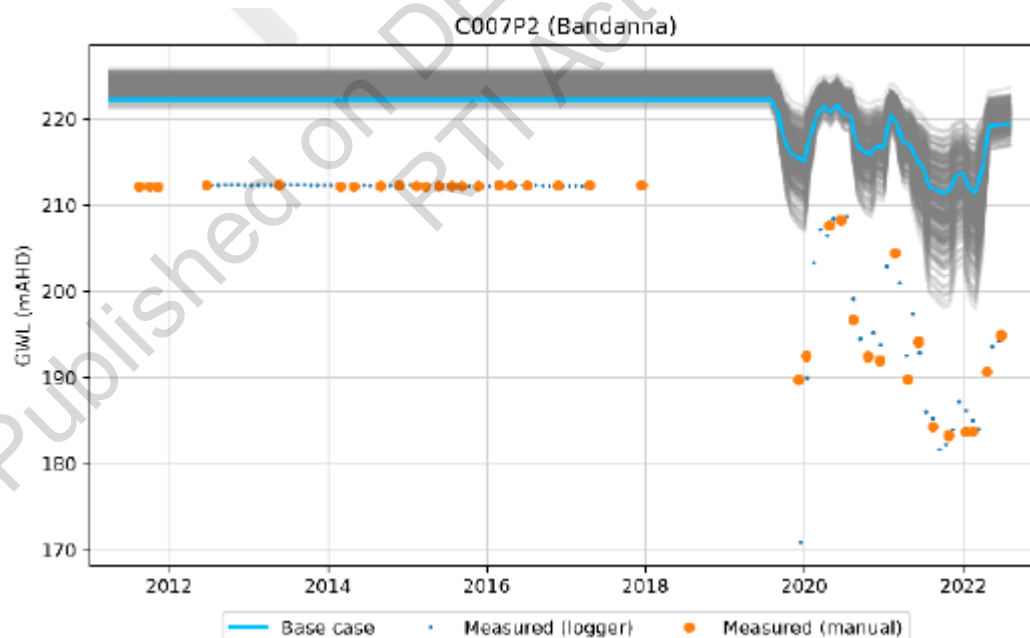
It appears that subsequently the model is unable to replicate these groundwater lows in this area in the pre mining period (pre 2019).

The model simulated initial heads for the calibration hydrographs as provided in Appendix C are therefore generally about 8 to 12 m higher than observed water levels in the Bandanna Formation and Colinlea Sandstone in this area. There are few Joe Joe bores in this area but in two bores located north-east of the current mining the initial heads are 7 m higher than observed water levels.

This is a poor representation of pre mining conditions and not a strong basis for model calibration and prediction in an area where dewatering conditions can provide excellent data for model calibration.

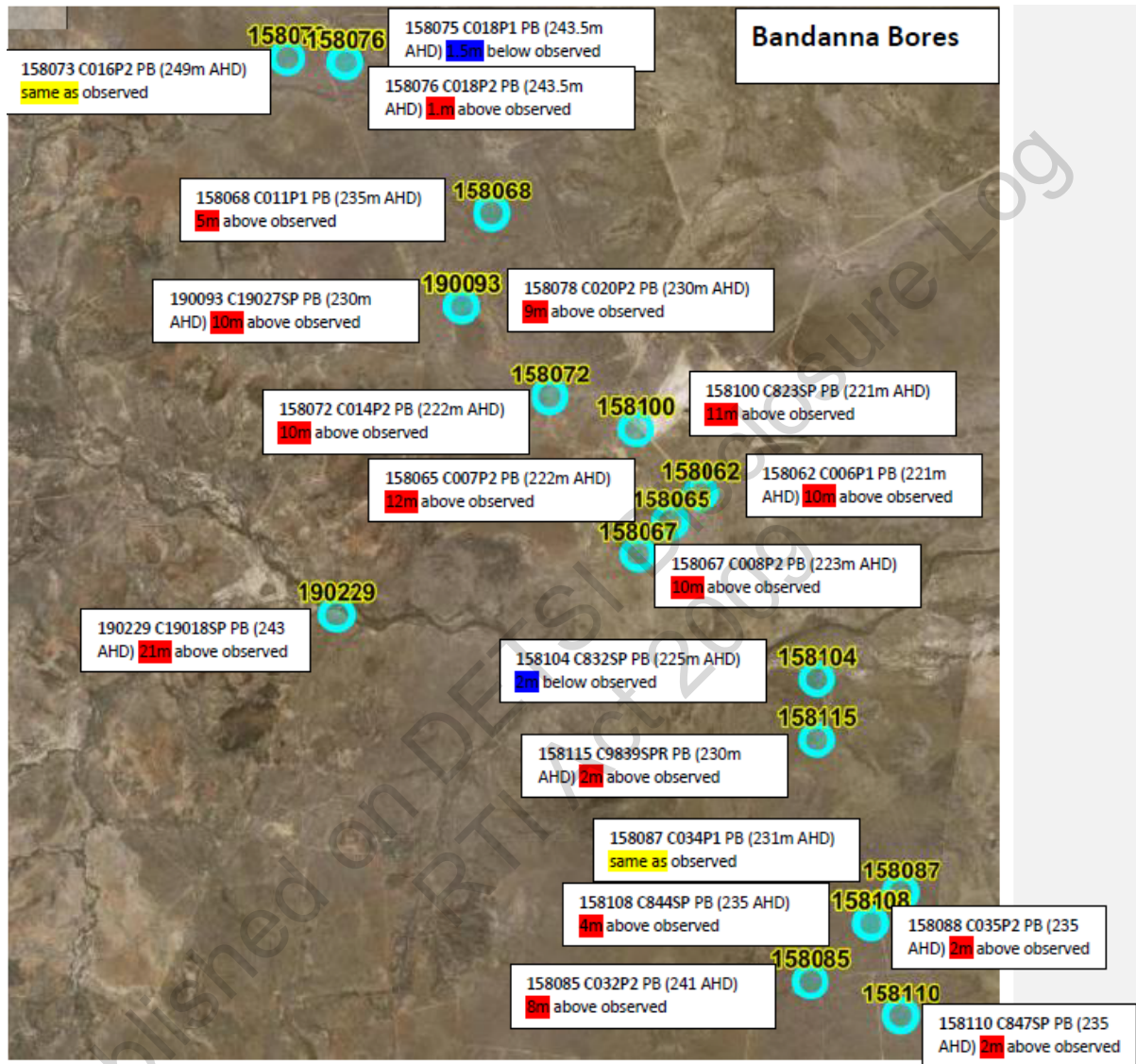


Red lines denote approximate area where model is predicting much higher initial heads than observed water levels in Bandanna, Colinlea and a couple of Joe Joe bores.



C007P2 - Example of an Appendix C calibration hydrograph where modelled initial heads are approx. 12 m higher than observed.

In each geologic unit the calibration hydrographs identified as representing that unit in Appendix C have been examined and an assessment of the variation between modelled base case initial head and observed water level made and then plotted on a map to understand spatial variation of these differences. An example is provided below for the Bandanna Formation. Similar figures are available in Appendix A for all geologic units except the Moolayember.



PB – Predicted Base case initial head

Initial Heads Alluvium

Appendix C contains 5 alluvial bores located in the Carmichael River alluvium. The base case initial heads for these five bores are between 6 and 12 m higher than observed water levels in these bores. This is a poor representation of the alluvial aquifer.

Modelled steady state contours are provided in the report for the Clematis Sandstone, AB Coal Seam and D Coal Seam only. It is not clear how the initial heads for the alluvium was determined.

Given this poor match between simulated and observed heads it is not clear how recharge and discharge processes in the alluvium will be impacted in the model, including its connectivity with Carmichael River surface flows, and how if at all the model can be used to provide commentary on environmental values associated with the river and the alluvium.

There is also concern about 5 other bores in Appendix C which are identified as being in the alluvium and may have been used in the model calibration. These bores appear to be in clayey material to the north of the Carmichael River and if they are in an alluvial aquifer it seems likely to be very poorly connected to the Carmichael River alluvium. Of these 5 bores in question 4 are always dry. It needs to be understood if these 5 bores have been used in the calibration process, if so that seems questionable.

Initial heads in Base Case Tertiary and Weathered Zone

Appendix C contains 5 bores identified as being in the Tertiary sediments only. The 4 northern bores have Base Case initial heads of between 3 and 12 m above observed water levels. The fifth bore, just south of Mellaluka Springs has an initial head 13 m lower than the observed water levels.

It is not clear how the initial heads were determined for the Tertiary sediments and it is not clear how those bores in Appendix C identified as monitoring the Tertiary and Joe Joe (composite) are used in the calibration process, i.e. representing which layer?

In the Weathered Zone, Appendix C contains 8 bores identified as being in the Weathered Zone. Three of these bores are always dry and it is not clear if they have been used for calibration purposes. Of the remaining 5 bores the model simulated initial heads for the Base Case are between 7 and 11 m higher than observed water levels. This would appear a poor match.

Initial Heads other geologic units/ other areas

Clematis- There is a generally fair to good match between initial heads and observed water levels.

Dunda Beds – There is a good match between initial heads and observed water levels.

Rewan Formation – There is generally a fair to good match in the upper Rewan between initial heads and observed water levels, particularly good near the Doongmabulla Springs. It is accepted that in parts of the Rewan, connectivity is poor and modelling of that connectivity can be challenging.

Joe Joe – Outside the area north of the river, previously discussed, the match between simulated initial heads and observed water levels is good.

Bandanna – outside the area north of the river, previously discussed, the match between simulated initial heads and observed water levels is fair to good. The exception is adjacent the Doongmabulla Springs and bore RN190229, C19018SP.

To develop steady state contours the bioregional assessment contours have been used (at DES' suggestion) to obtain regional water levels and in particular those off to the west. This appears to have resulted in an over estimation of initial heads at 190229, near Moses springs of 21 m.

The regional Bioregional Assessment contours in the Bandanna are primarily driven in this area by a drill stem test in coal seam gas exploration hole, Shoemaker No.1 (located 3.5 km north-west of 190229). It had an estimated head in the Bandanna of 245 m AHD. Given that the water level in an open monitoring bore (190229) is likely to be more accurate than that of a drill stem test, in a bore not primarily constructed to obtain water levels, it is considered that more weighting should be given to the water level in 190229 than Shoemaker No.1.

Colinlea- outside the area north of the river, previously discussed, the match between simulated initial heads and observed water levels is fair to good.

Ability to model dewatering impacts

The 2022 Annual Groundwater Monitoring report identified the following bores as being impacted from dewatering based on the observed water level trends in the bores.

Based on the calibration hydrographs provided in Appendix C a comparison of observed vs modelled water levels (Base Case) is provided below.

In summary the model base case may be slightly under predicting drawdown in bores in the AB seam, C Seam and D seam, close to the dewatering bores.

It also appears to have some difficulty predicting impacts in bores which are not directly accessing the seams and may be in less permeable interburden above or below the seams. In these instances (eg C006P1 and C834SP) there is evidence to suggest the model is slightly over estimating impacts.

Further from the dewatering the model appears to be predicting similar of slightly higher impacts then observed.

It is also noted that the base case simulated drawdowns are greater in C008P2 than in C007P2 when C008P2 is well west of C007P2 (adjacent a dewatering bore).

Bandanna

Bore Number	RN	Observed max DD (m)	Base case max DD	Simulated Initial head (Base Case) above observed (m)	Comments
C006P1	158062	8	19	10	Located in interburden above C seam. Has possibly led to underpredicted dd
C007P2	158065	30	10	10	AB Seam
C008P2	158067	25	20	10	AB Seam. Problem here in that more drawdown is predicted in the bore further away from dewatering than C007P2.
C823SP	158100	27	16	11	C seam

C832SP	158104	3	5	-2	C seam
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Colinlea

Bore Number	RN	Observed max DD (m)	Base case max DD	Simulated Initial head above observed (m)	Comments
C006P3R	158063	31	22	8	D Seam
C180112SP	158093	49	21	1	Sand below D seam
C827SP	158102	37	39	9	E Seam
C833SP	158105	5	5	-1	D Seam. Model not picking up differences in 833 and 834, different units different dd but model says the same.
C834SP	158106	2.5	5	0	Clay and siltstone below D seam
C840SP	158107	2	3.5	2	Sand below D seam
C19026SP	190091				Not used in calibration, replaces C007P3
C19029SP	190604				Not used in calibration, replaces C180114SP

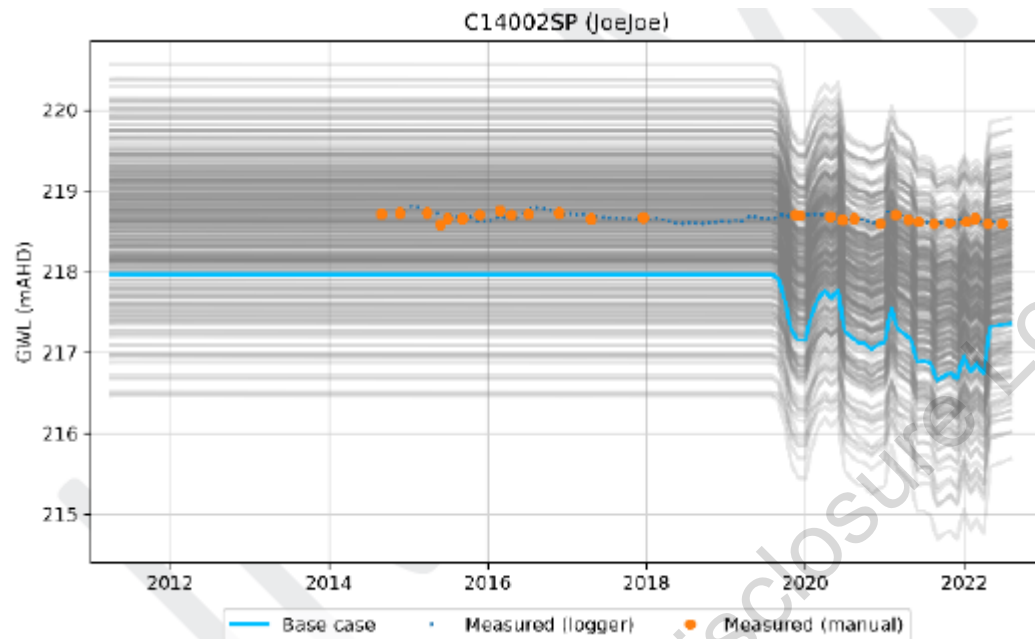
Overpredicting drawdown extent and drawdown

At the southern end of the lease there are predicted drawdowns in the Colinlea from dewatering when there are none observed (C19004SP and C19003SP). There are also predicted drawdowns in the Joe Joe, caused by dewatering, in a number of places in bores (south lease area and down towards Mellaluka Springs) when none had previously been considered to be occurring.

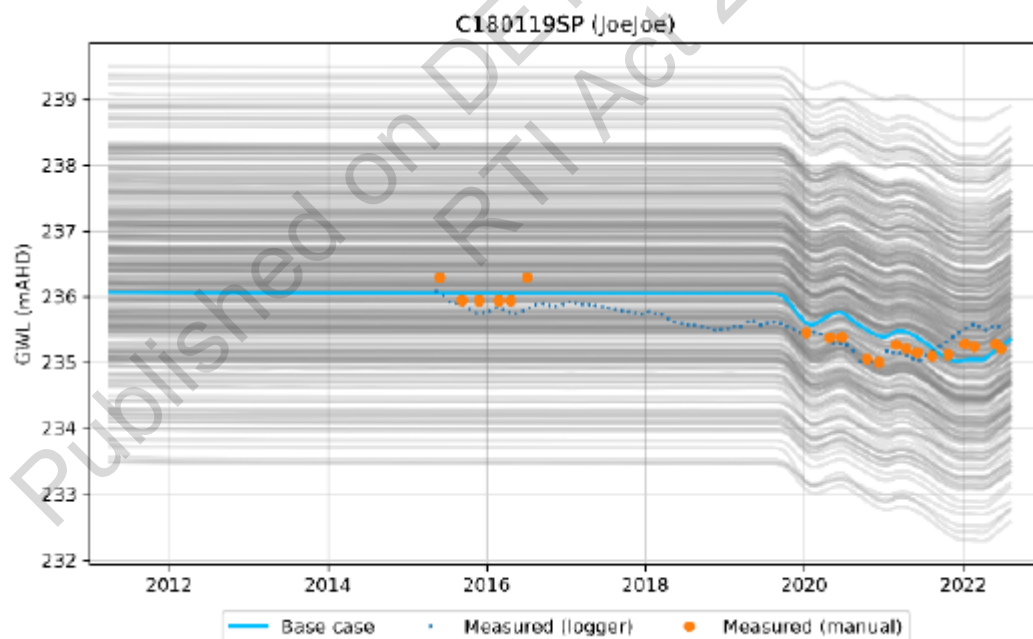
Part of the problem may be that there is some drawdown in some Joe Joe bores to the south caused by local landholder use and the model does not incorporate landholder use so it is trying to replicate the drawdown using dewatering impacts. Perhaps this problem could be addressed by incorporating some landholder use.

The other concern here is the significant increase in predicted impacts in a number of formations including the Joe Joe. In determination of previous groundwater level thresholds in Joe Joe bores adjacent Mellaluka Springs the maximum predicted drawdown had been determined to be less than 1 m. In the new model open cut only scenario, Appendix A in the GMMP Review report, the

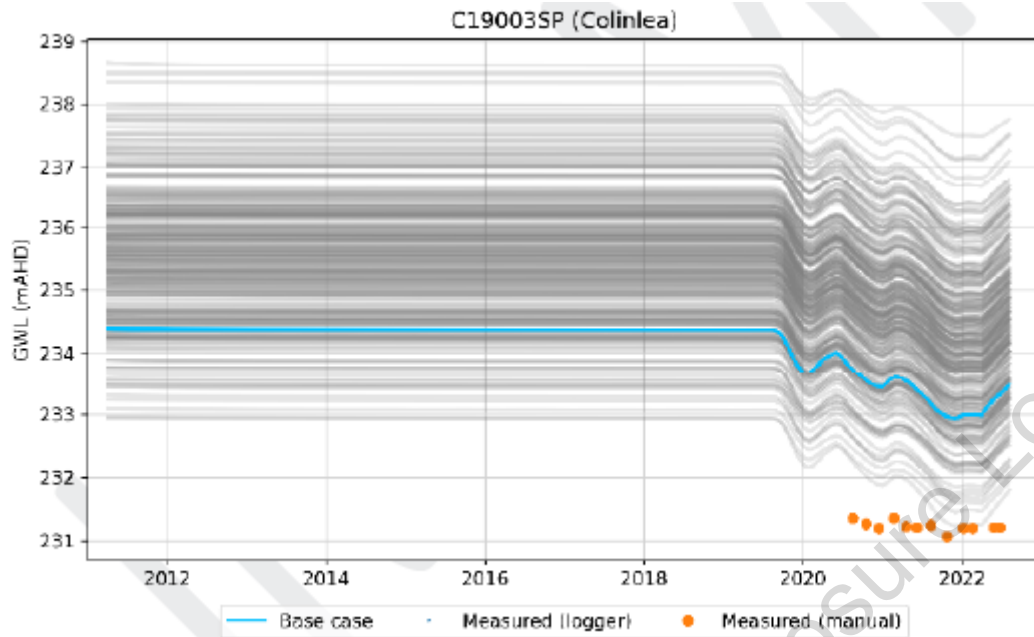
maximum predicted drawdown is now 60 to 80 m in these same Joe Joe bores. Is that realistic or has the model been unduly influence by not including landowner water use in this southern area.



RN165366 Joe Joe bore located south-east of current mining approx. 5 km from nearest dewatering bore. Predicted drawdown from mining when none occurring.



RN158096 Joe Joe bore located 21 km south of the Carmichael River. Some oscillation of observed groundwater levels is occurring and the model is simulating impacts from mining.



RN190228 Colinlea bore located on southern boundary of lease, 15 km south of Carmichael River. No apparent decline in observed groundwater levels and model is simulating impacts from mining.

Calibration Targets

Section 4.1.1 of the draft model report states:

A total of 11,443 history-matching targets were employed. These were subdivided into the following groups:

- *239 hydraulic head targets, grouped by HSU;*
- *11,202 head-change targets, grouped by HSU; and*
- *2 flux targets.*

It is further stated that the weights of the hydraulic head targets were increased to double the relative computational effort towards matching absolute groundwater levels.

However, the number of heads targets vs head change targets is very low and it is not clear if the calibration process may be overly biased towards head change rather than a mixture of head change and absolute heads.

Dewatering Volumes used in modelling

Section 3.5.5 Mining Activities states:

i Production bores

The MODFLOW well (WEL) package is employed to simulate groundwater abstraction from mine dewatering bores. Measured groundwater abstraction for each bore is incorporated in the monthly stress periods in the history-matching period from August 2019 to March 2022 (Table 3.2).

On a number of occasions Bravus and EMM have been asked how they will attribute dewatering volumes to each layer in the model given the dewatering bores typically take water from multiple model layers. DES had been advised that this process would be explained in the model report. It does not appear to have been.

Uncertainty Analysis Presentation of Results

Appendix D provides hydrographs of predicted long term water levels for the Open Cut only scenario.

In the DSC springs the maximum predicted drawdown is about 0.10 m.

The presentation provided by Bravus on 31 January 2023 demonstrated that at an assortment of the DSC springs, in 0% of the predicted model runs the drawdown at these springs exceeded 0.2 m.

However, in section 5.1.1 of the model report, the subject of assessing the likelihood of drawdown, is discussed. Table 5.1, reproduced below provides explanation of the approach.

Table 5.1 Combined numeric, narrative, and visual approach for assessing the likelihood of drawdown

Percentile band (outcomes ranked from small to large)	Colour code	
<P10		It is very unlikely that drawdown exceeds the threshold
P10 to P33		It is unlikely that drawdown exceeds the threshold
P33 to P67		It is as likely as not the drawdown exceeds the threshold
P67 to P90		It is likely that drawdown exceeds the threshold
>P90		It is very likely that drawdown exceeds the threshold

The model report states:

the approach is based on Table 2 of the IESC guidance note on uncertainty analysis (Middlemis and Peeters 2018).

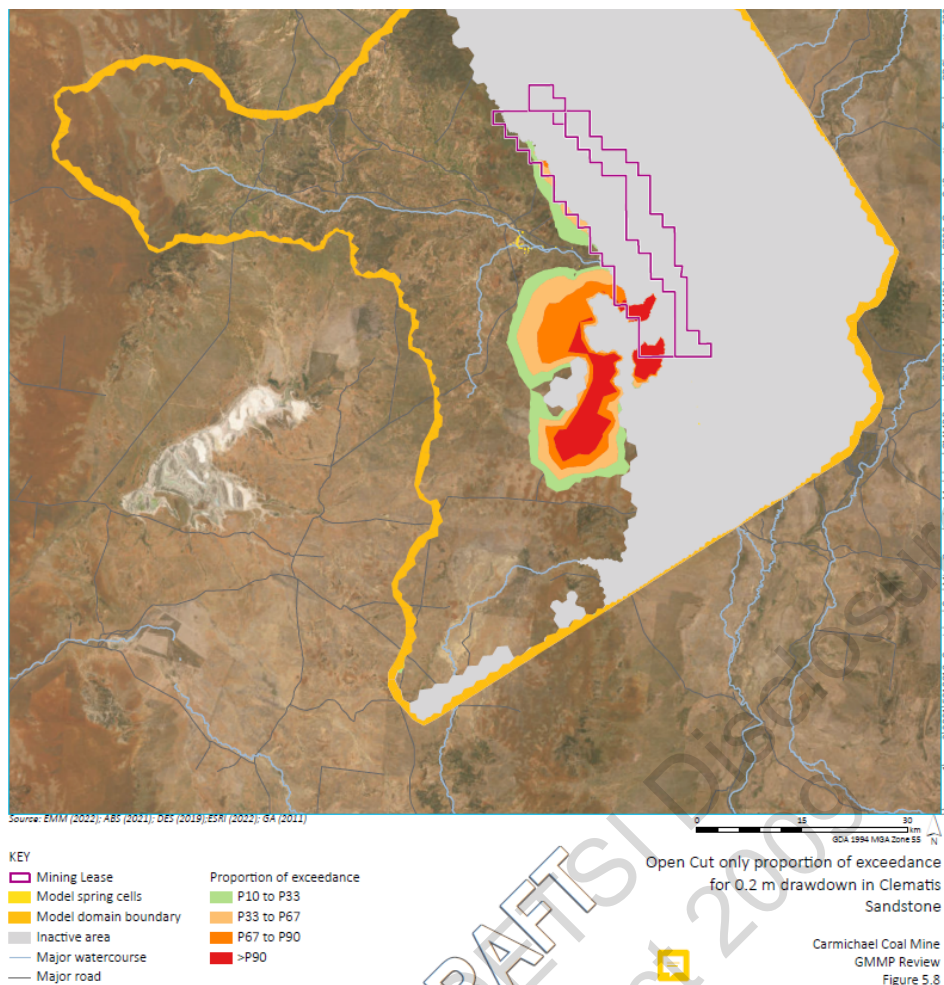
In Figure 5.8, reproduced below, the proportion of exceedance of 0.2 m drawdown (open cut only scenario) is mapped for the P10 to >P90 areas. Less than P10 is not mapped and it is not clear if everywhere else is inferred to be less than P10 or how that is interpreted.

As a result, the model report then states:

Figure 5.8 shows the contour intervals for the likelihood of exceedance of the 0.2 m drawdown threshold in the Clematis Sandstone for the open cut only scenario. The 'very likely' region is in the south to southwest of the mine lease and away from sensitive receivers. All DSC springs fall within the 'very unlikely' category, meaning that the springs are predicted to be under little risk of experiencing drawdown in breached of the drawdown threshold.

This may just be a different way of presenting the same outcomes but it can be somewhat confusing or misleading to firstly see that none of the uncertainty runs are predicted to exceed a drawdown of 0.2m but then in the text of the report it says that it is very unlikely that drawdown will exceed 0.2m at the springs.

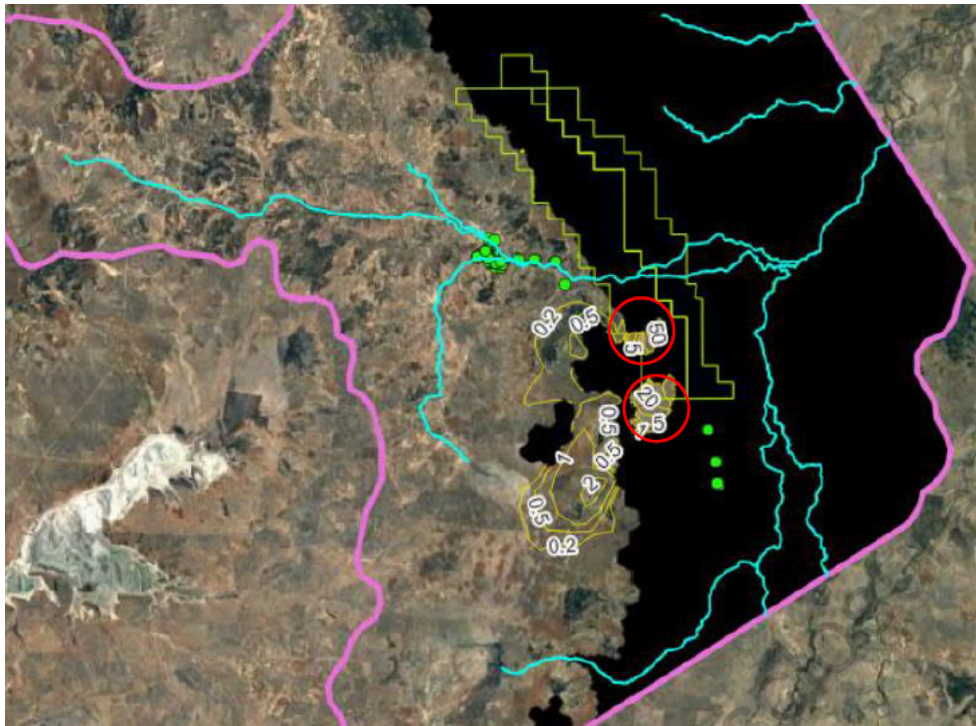
Further advice should be sought on this matter and possibly clarification of how the two pieces of information should be interpreted.



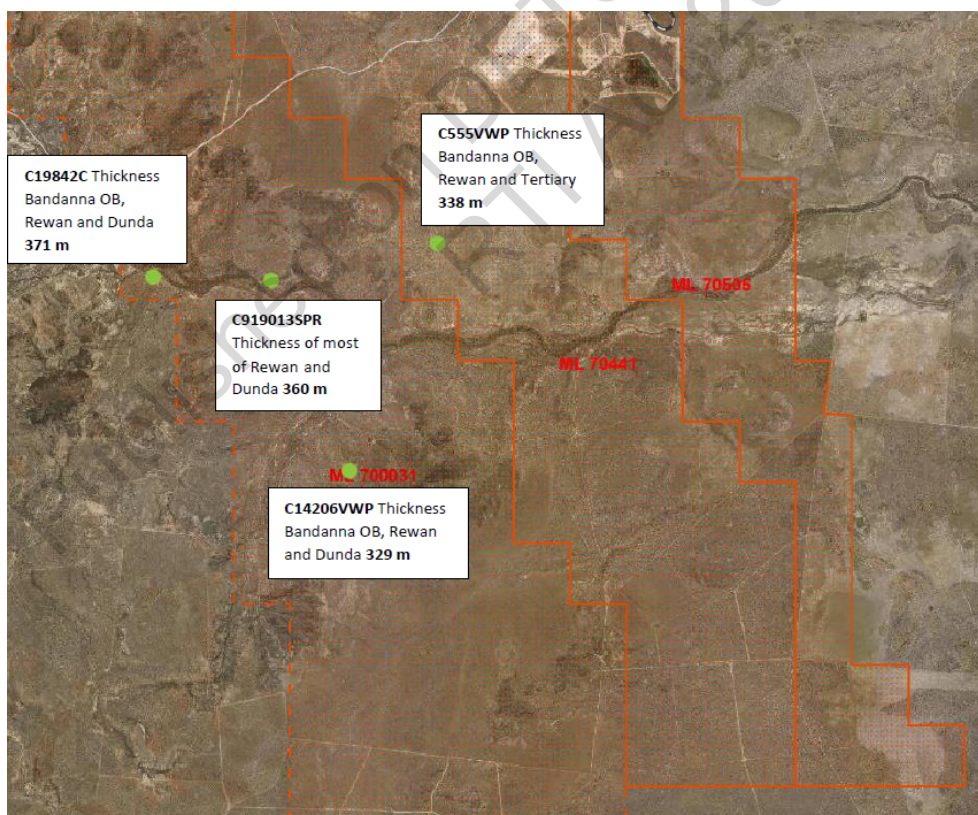
Geology, extent of Clematis and Dunda Beds

There is an area on the south-western edge of the mining lease where the extent of the Clematis Sandstone has been reinterpreted based on the Titus modelled geological layers. Some interpretation has occurred when using the geological layers to update the numerical model layers.

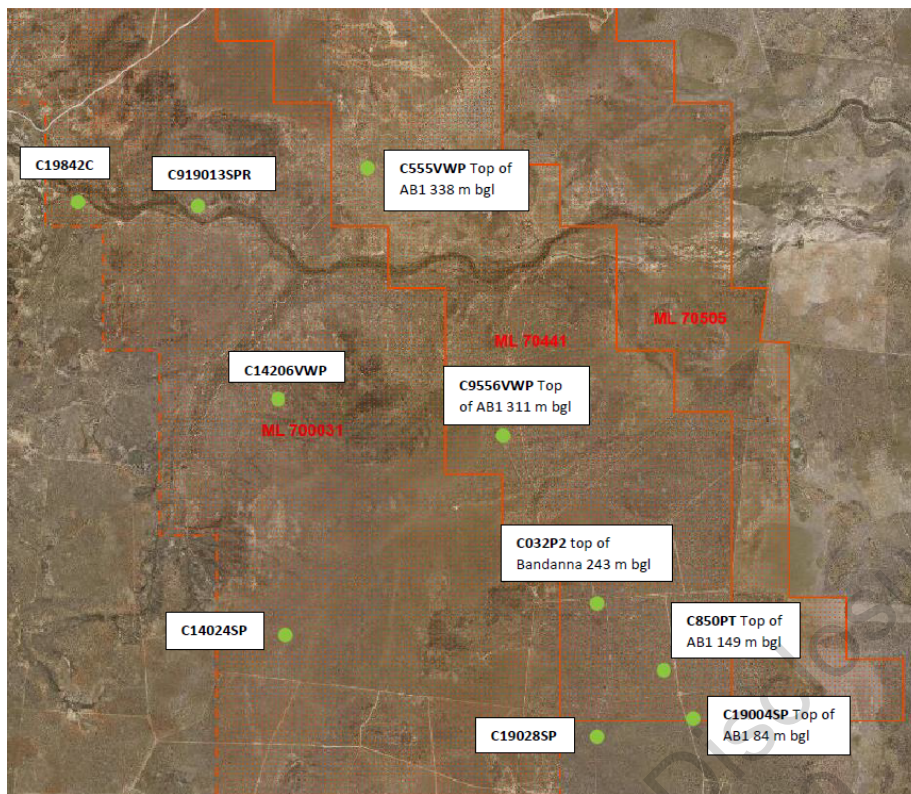
As a result, there are some narrow Clematis extents that are now predicted to intrude into the mining area, where previously they had not. This Clematis mapping was explored further.



The orange circles represent the areas of Clematis Sandstone which are now mapped and modelled as extending into and adjacent the lease area



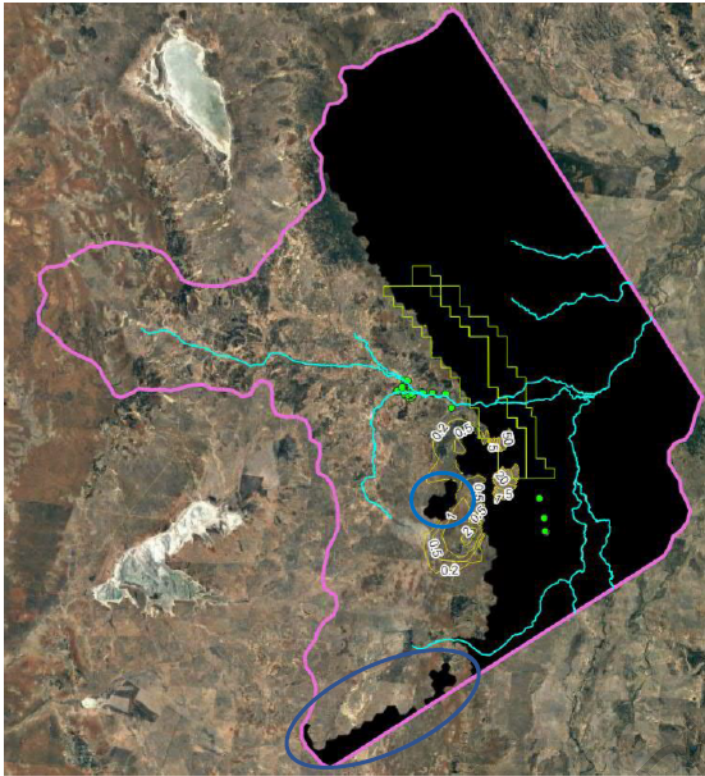
Determining average thickness of the Bandanna overburden (above AB seam) Rewan and Dunda Beds in the area, which is some 330 m in this area.



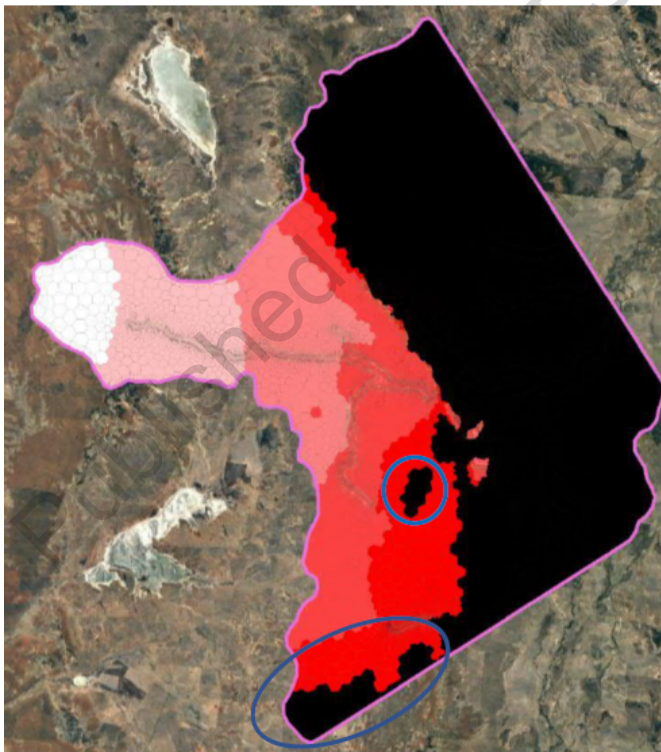
Determining depth to top of AB Seam in the south-western lease area

Based on the average depth of cover above the AB seam and the depth to the AB seam in this area, there appears to be no evidence of Clematis sandstone jutting out into the lease area as has been mapped. That needs review based on actual data.

Other areas of concern with Clematis and Dunda mapping



Clematis



Dunda

The circled areas show areas of apparent 'holes' in the Clematis and Dunda which are not supported by existing mapping available in the area.

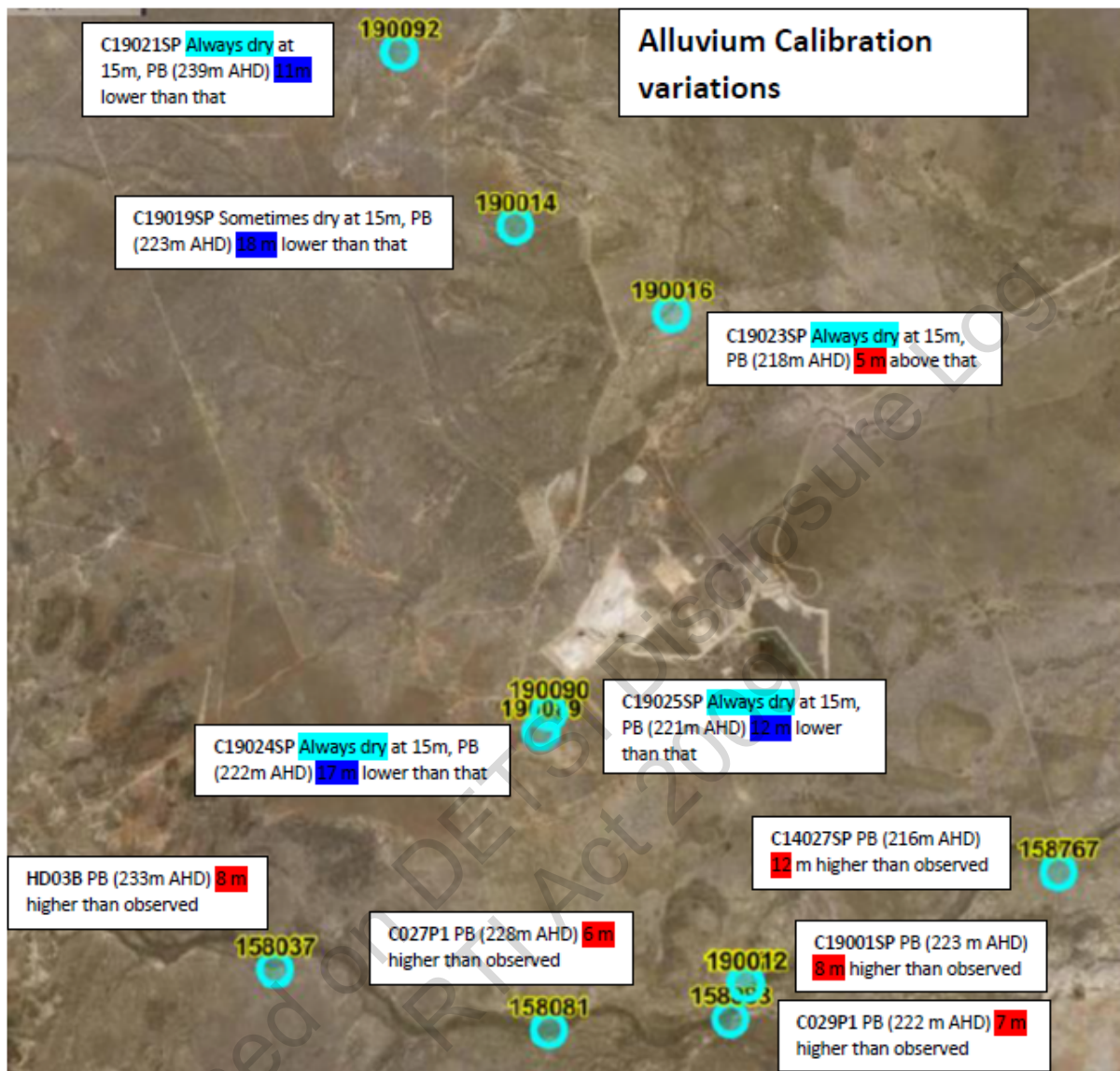
Section 7, Summary and recommendations from the model report states the following:

As noted by Murray (2022), tying in the local Rewan Research model to the Bioregional assessment model highlighted some very significant mismatches and worrying errors. Murray recommended that a full review of the broader Bio-regional assessment model is warranted.

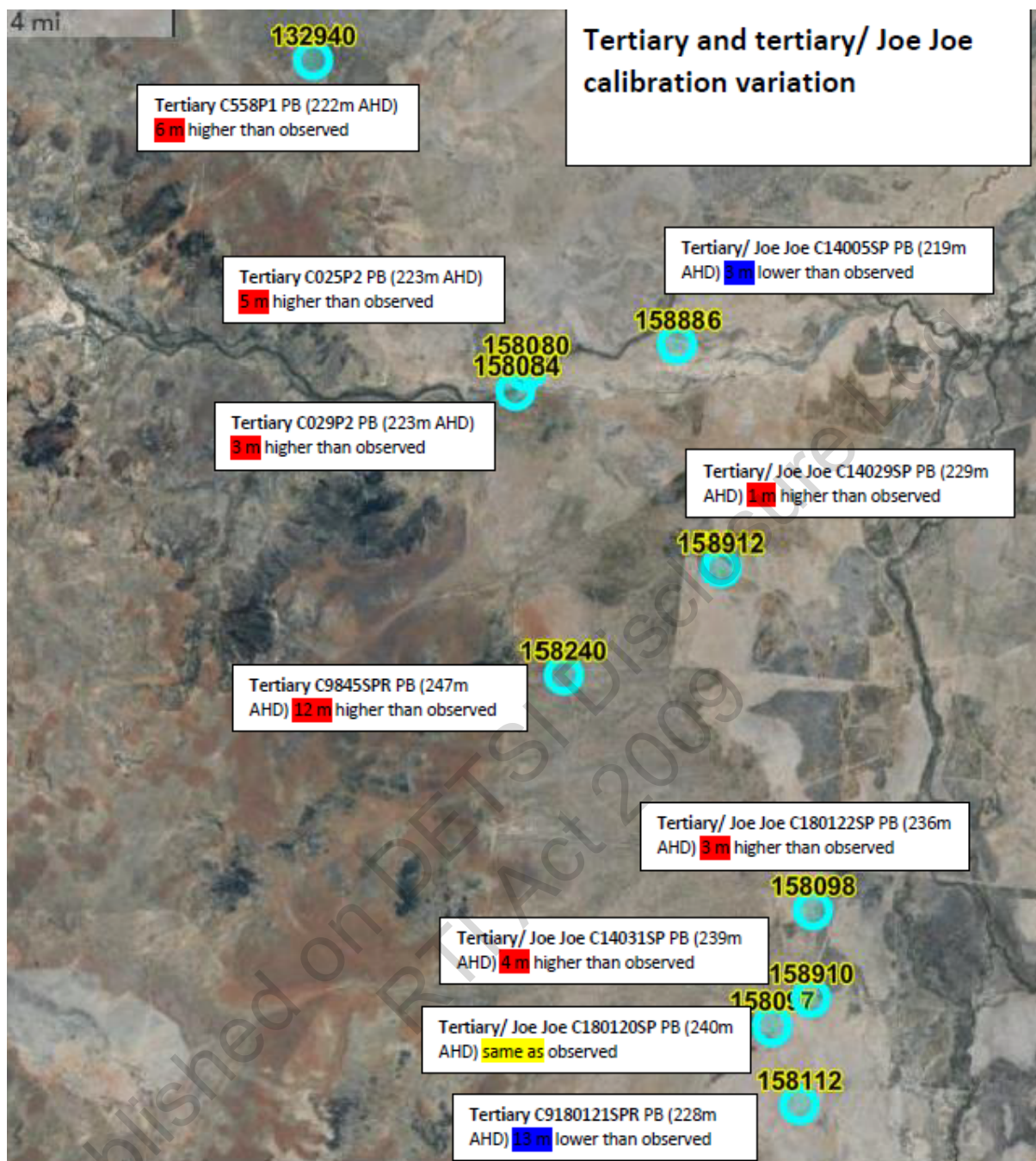
This appears to be the problem with the holes identified in the maps above. It is noted that there is now a lot of additional data in this area including from CSG holes and it is considered that a more realistic representation of the Clematis extent could be provided in the model area than has been presented.

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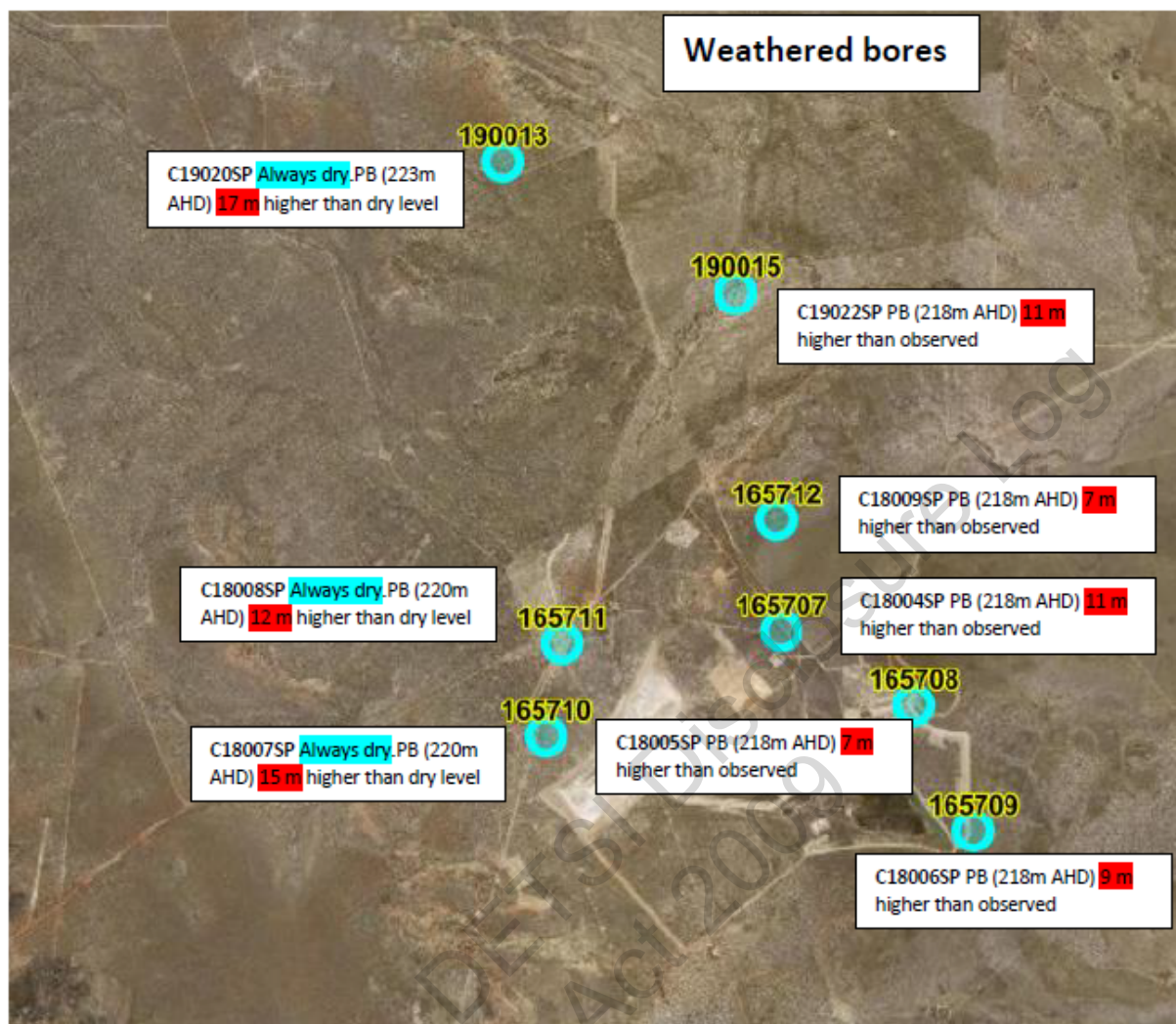
Appendix A

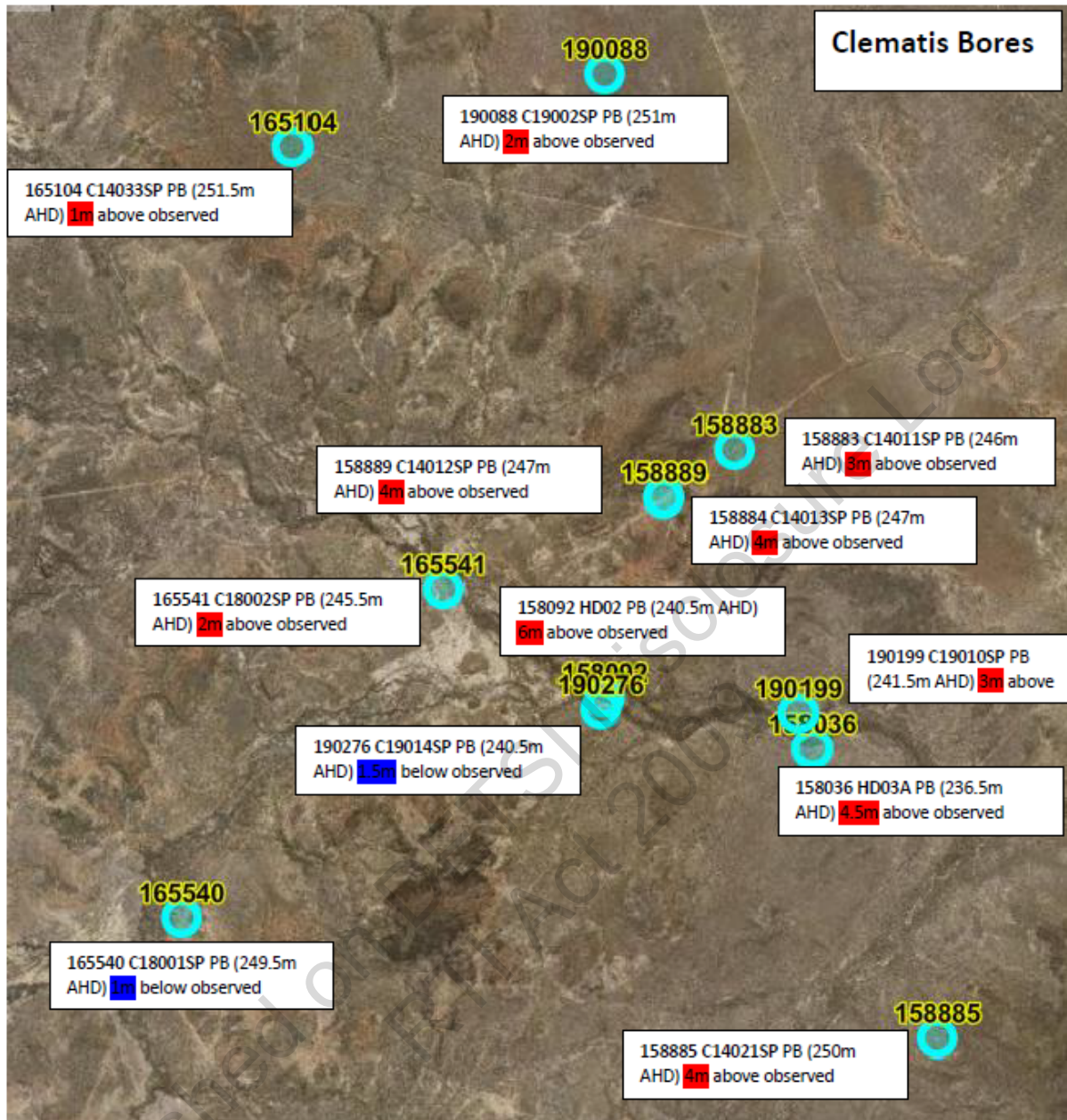


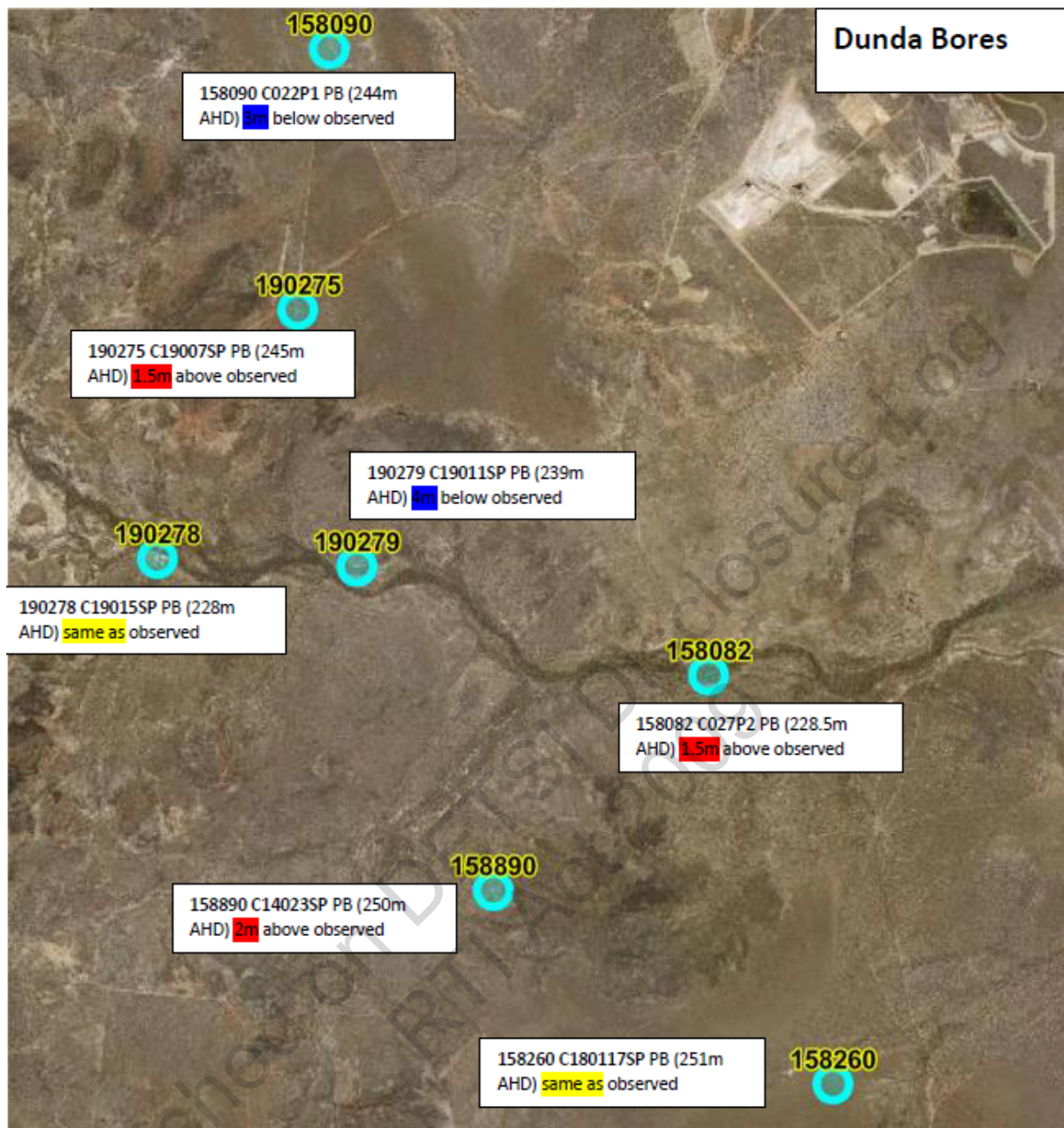
PB – Predicted Base Case initial head

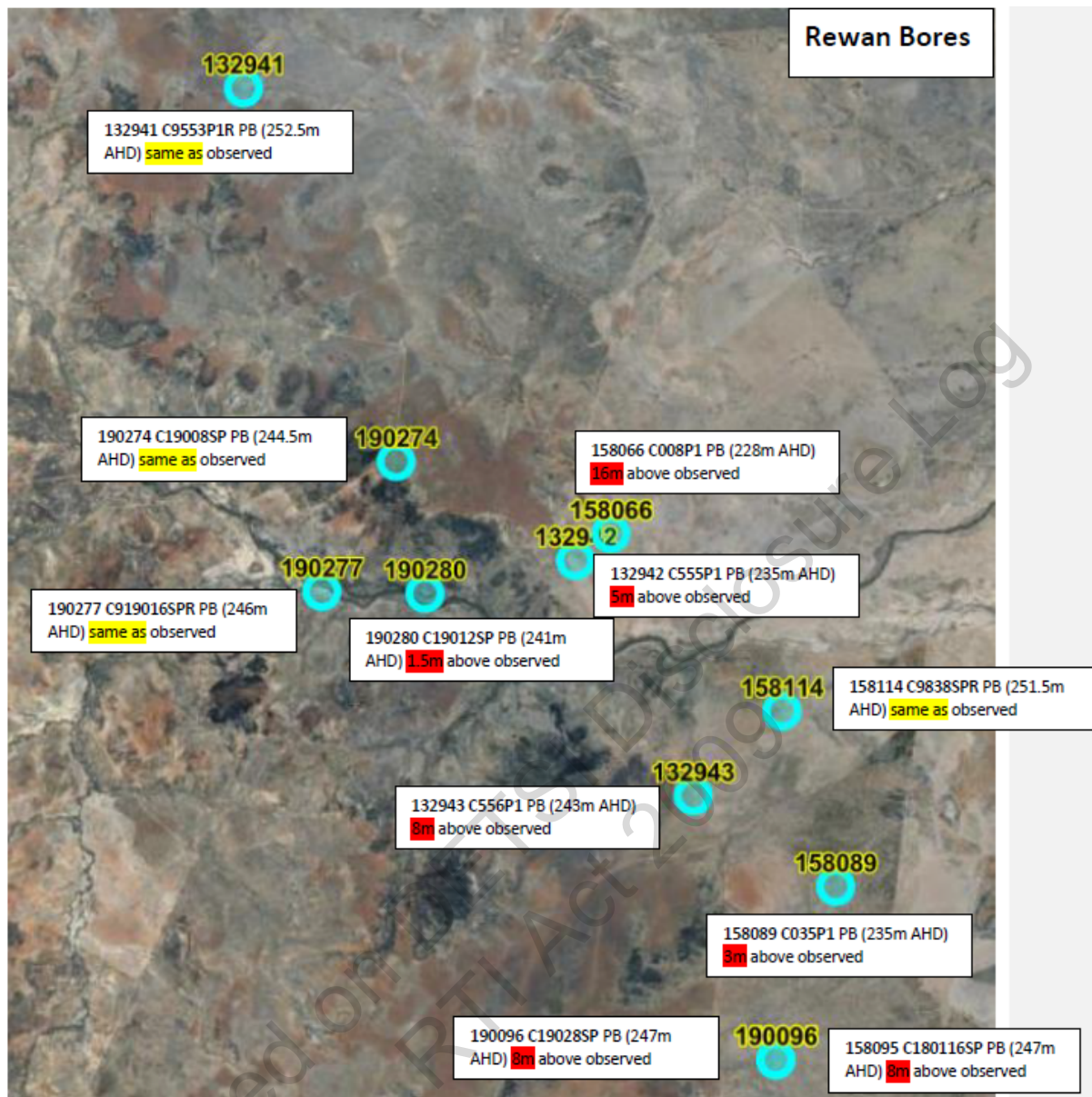


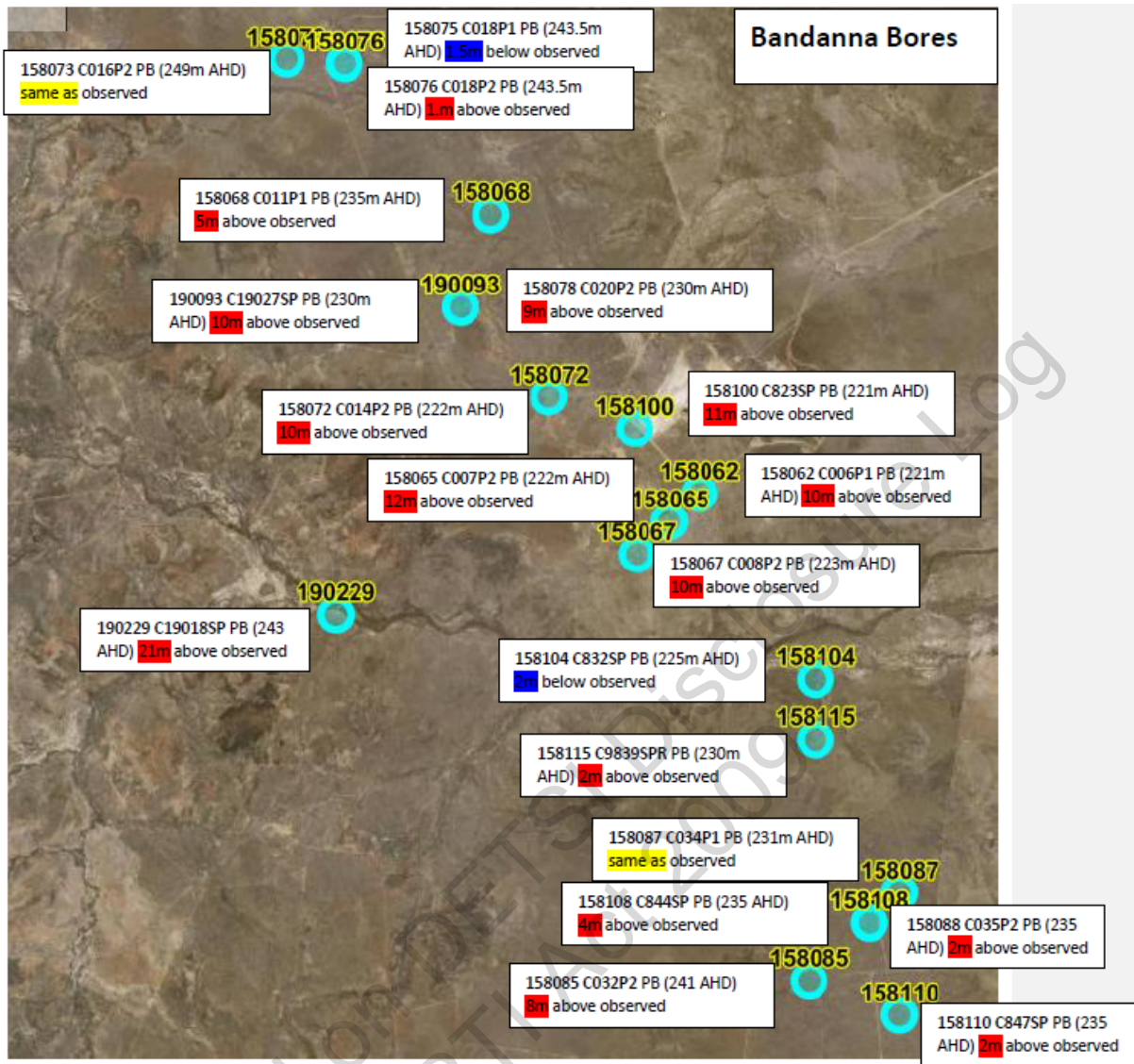
Two sets of bores, those representing the Tertiary Sediments and those accessing both Tertiary and Joe Joe described as composite in Appendix C and not clear what layer they represent in the model

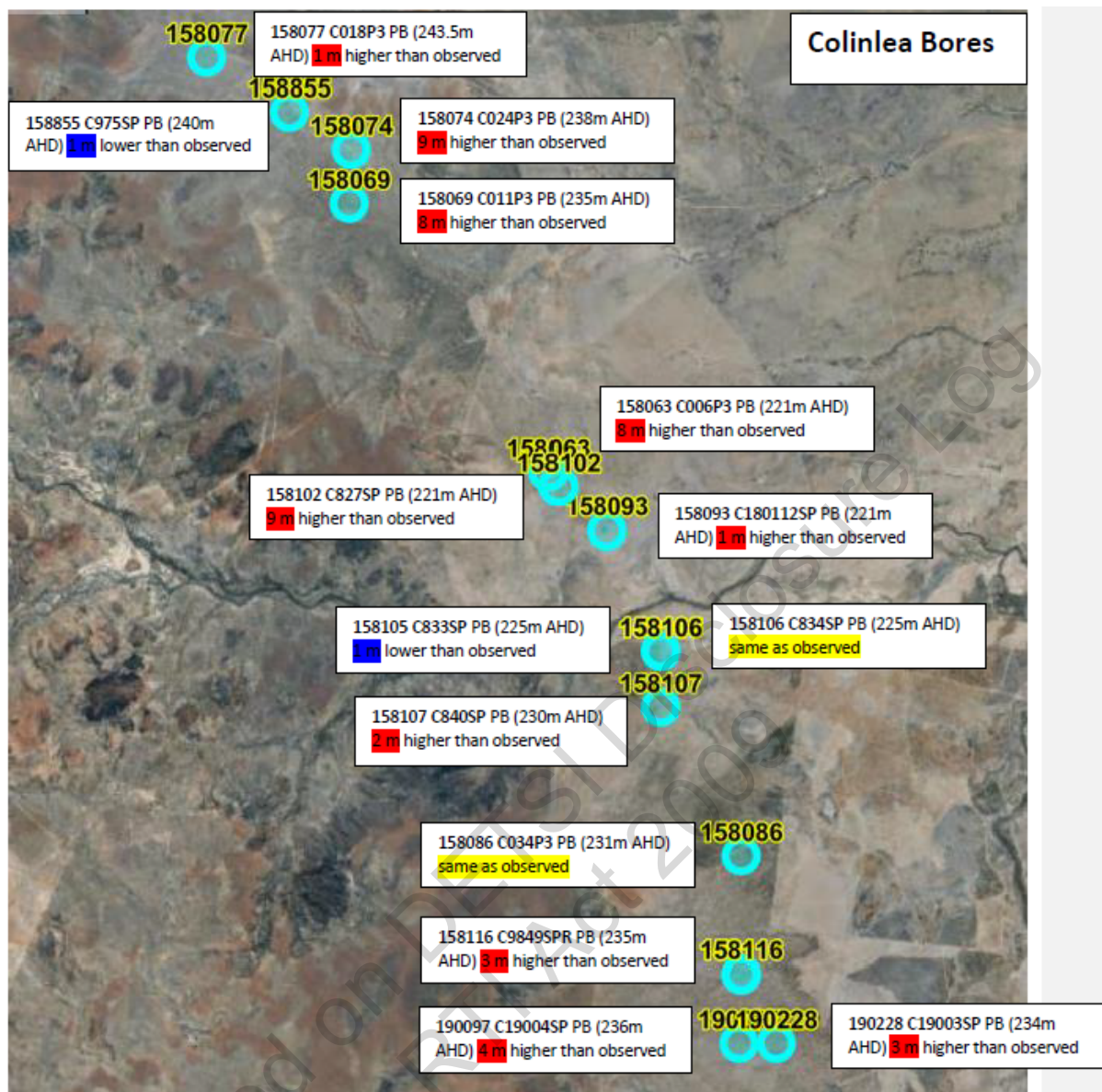




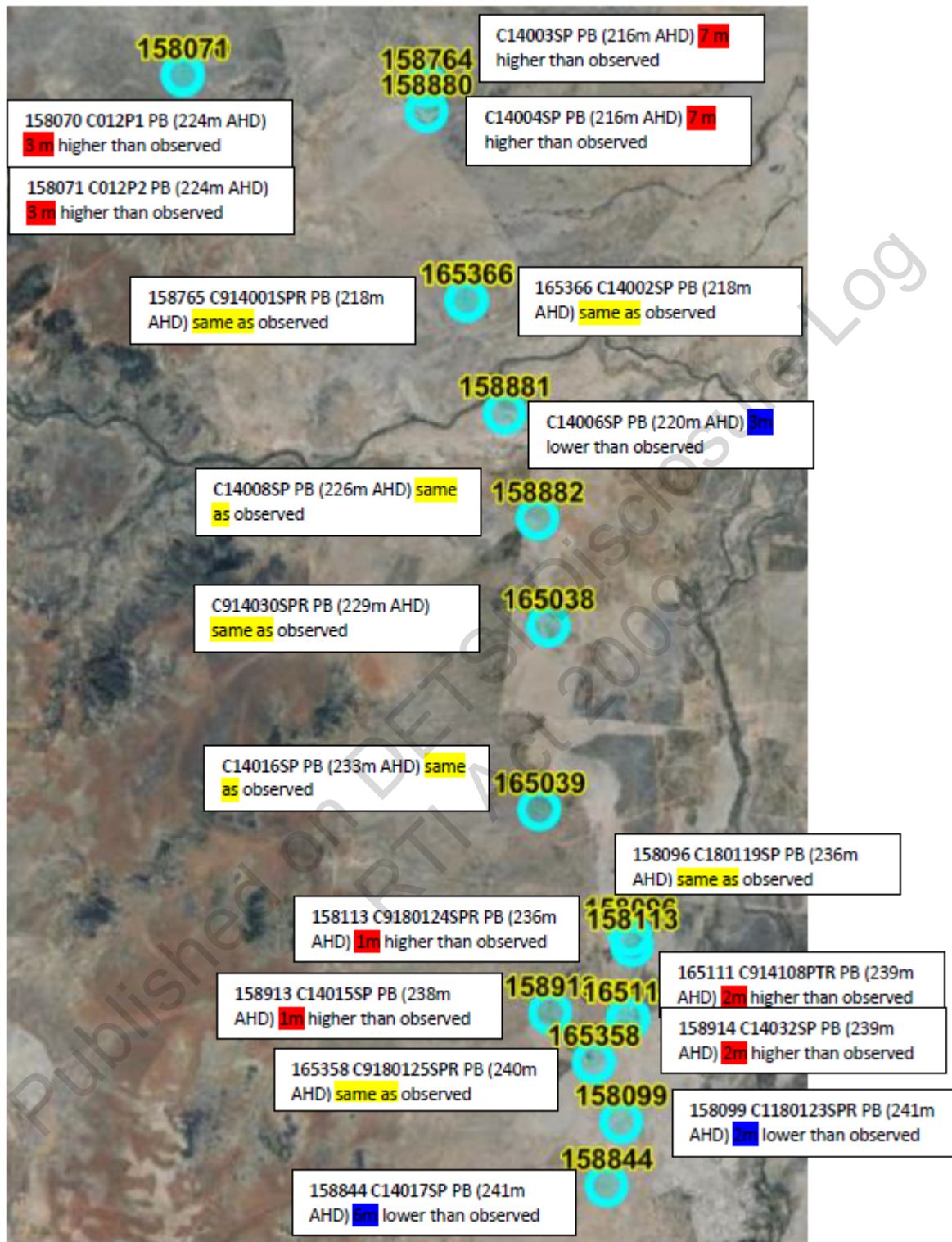








Joe Joe Bores



CSIRO/GA Questions

Model Report

1. Does the uncertainty analysis presented in the GW Review report meet the IESC guidelines and will it provide an acceptable/realistic range of potential impacts?
2. Is the methodology used to model the impacts of long wall mining under the SEIS B scenario adequate and appropriate, particularly with respect to prediction of impacts to the Doongmabulla Springs Complex?
3. Has the use of pilot points resulted in a more accurate representation of parameters instead of using one parameter value per layer?
4. Is the model cell size of 500m in the mining areas appropriate especially with respect to identifying longterm impacts from residual voids post mining?
5. Do the initial heads determined in the history matching process adequately represent the observed groundwater heads and groundwater system. In particular:
 - Does the model represent the pre mining groundwater lows observed north of the Carmichael River in the Bandanna Formation, Colinlea Sandstone and Joe Joe formation? Does the model incorporate findings from the conceptualisation?
 - Do the initial heads and simulated groundwater levels in the Carmichael River alluvium adequately represent that aquifer and if not, how might this affect the understanding of surface water-groundwater interaction? Has the use of dry bores north of the river affected the process?
 - Are the initial heads in the Tertiary sediments and Weathered zone representative of the observed groundwater system in these units? Has the use of dry bores in the Weathered zone affect the process?
 - Has the use of many more head change targets than absolute heads in the history matching process resulted in poorer matches between simulated initial heads and observed heads?
6. Has the modelling approach which does not include landholder water use from bores, in particular the Joe Joe to the south of the lease, resulted in predicted mining impacts in this area that match the head change targets?

The GMMP Review report, Appendix A now includes predicted drawdowns in Joe Joe formation bores in the Mellaluka Springs area of between 60 and 80 m for the open cut only scenario. This is an increase from previous predicted drawdowns (under the 2013 SEIS model) which were less than 1 m for these same bores. Are these increases realistic? Have they been influenced by the lack of landholder water use being included in the model in this area?
7. Does the modelling of the open cut mining only scenario (including parameters used and methodology of the uncertainty analysis) provide an appropriate level of confidence in the predicted impacts to DSC?
8. What additional geological work with respect to the extent of the Clematis Sandstone and Dundas Beds is required to improve the confidence in the modelling outputs for the optimisation model?

9. Have all the additional works as recommended by CSIRO/GA in 2019 been addressed (whether completed or not) to your satisfaction in particular to support the identification of the source(s) aquifer(s)?
10. Has sufficient isotopic work been undertaken to advance our understanding of the source aquifer? GABSprings Research Report 1.
11. What matters must be addressed to the model methodology prior to undertaking an Optimisation model of mining activities to ensure no greater than 0.2m drawdown at DSC?

GMMP report

1. Does CSIRO/GA support the use of GW thresholds based on the open cut only model scenario?
2. Do you support the Bravus proposed additional monitoring bores and locations? Do you support DES recommendations for additional bores? Any additional bores?
3. What action should be taken if the actual monitored rates of groundwater drawdown are faster than predicted?
4. In order to address ongoing and upward trending water quality trigger exceedances – what do you recommend as an appropriate action?
5. Please provide advice on the suitability and reliability of the use of VWP monitors.

DES Proposed Additional Monitoring bores

Colinlea Sandstone – D Seam – standpipe monitoring bores required

Site 1

On the western boundary of ML70441 in a location that won't be mined out. This should be located between C007P3 (RN158064) and Doongmabulla Springs. (In the January 2023 version of the GMMP review report Bravus propose new bore number 5 at this location. That is supported by DES).

Currently there are no Colinlea Sandstone monitoring bores (standpipe bores) west of the dewatering bores. In order to better understand the propagation of drawdown from the mine towards the Doongmabulla Springs there should be a Colinlea Sandstone monitoring bore on the western boundary of ML70441.

Site 2

Adjacent C19031VWP (RN190605), between Moses and Little Moses Springs.

There should be a monitoring bore (standpipe bore) in the area of C19031VWP (RN190605) as given the unreliability of the existing VWP bores there can be no guarantee that data from this VWP is representative of the Colinlea Sandstone. This bore is to be located between Moses and Little Moses springs, would provide a reliable head in the Colinlea in this area and also provide information on any propagation of drawdown from the mine to this area in the Colinlea. It would also provide valuable information for developing initial heads information in this western area of the groundwater model.

Site 3

Adjacent C558VWP (RN158596), 4.7 km north-west of the northern most current dewatering bore. (Bravus propose monitoring bore 1 at this location in the GMMP review. That is supported by DES)

There is a lack of Colinlea Sandstone monitoring bores adjacent the northern dewatering bores and immediately north of the dewatering bores. C19026SP (RN190091) and C006P3R (RN158063) are adjacent the southern dewatering bores. The closest monitoring bore north of these two monitoring bores is C011P3 (RN158069) some 11 km to the north-west. No impact from mining is being noted at C011P3 so existing propagation of drawdown north cannot currently be tracked.

Site 4

South of Carmichael River, approximately half-way between C840SP (RN158107) and C034P3 (RN158086) which are approximately 5.8 km apart.

There is a gap between C840SP (most southerly monitoring bore considered impacted, by Bravus in the 2022 annual monitoring report, based on observed water level trends) and C034P3 which is some 5.8 km south of C840SP. Tracking the impact of mining south will therefore also soon become difficult.

Site 5

Directly west of Mellaluka Springs as advised by Bravus in the GMMP review although they suggested not a priority at this time. DES consider that it is.

There are currently no Colinlea Sandstone monitoring bores south of the mining lease.

There is a need in this area to:

- understand the relationship between the Colinlea Sandstone and the Joe Joe and Tertiary
- Understand the impacts of local landholder use on water levels in this area and the challenges in unpacking which stress is causing impact

Therefore, the sooner baseline data is available from the proposed Colinlea Sandstone and Bandanna Formation bores in this area, the better. In the GMMP Review Bravus propose a monitoring bore in this area in the future but not until impacts are noted at the southern boundary of the mining lease. That proposal is not supported by DES as it is considered that there is a need for a monitoring bore at this location now.

Site 6

Adjacent C14012SP (RN158889) (approx. 3.6 km north of Little Moses Spring) as advised by Bravus in the GMMP review, proposed site 2. (This proposal is supported by DES)

This site would provide understanding of groundwater heads in the Colinlea Sandstone north and north-east of the Doongmabulla Springs allowing more accurate development of initial heads for modelling in this area. It would also provide information on any propagation of drawdown from the mine to this area in the Colinlea Sandstone.

Bandanna Formation – AB seam – standpipe monitoring bores required

Site 7

On the western boundary of ML70441 in a location that won't be mined out. This should be located between C008P2 (RN158067) and Doongmabulla Springs. (In the January 2023 version of the GMMP review report Bravus propose new bore number 8 at this location. That is supported by DES).

To the west of the dewatering bores there are only two Bandanna Formation monitoring bores. C008P2 (RN158067) which is located 1.4 km west of the dewatering bores and showing significant impacts from mining and bore C19018SP (RN190229) located 10km west of C008P2, adjacent Moses Springs. In order to better understand the propagation of drawdown from the mine towards the Doongmabulla Springs there should be a Bandanna Formation monitoring bore on the western boundary of ML70441.

Site 8

Adjacent C14012SP (RN158889) (approx. 3.6 km north of Little Moses Spring) as advised by Bravus in the GMMP review, proposed site 6. (This proposal is supported by DES)

This site would provide understanding of groundwater heads in the Bandanna Formation north and north-east of the Doongmabulla Springs allowing more accurate development of initial heads for modelling in this area. It would also provide information on any propagation of drawdown from the mine to this area in the Bandanna.

Site 9

South of Carmichael River, approx half-way between C9839SPR (RN158115) and C034P1 (RN158087) which are approximately 5.8 km apart.

In the Bandanna Formation there is a gap between C9839SPR (almost considered impacted by Bruvus in the 2022 annual groundwater monitoring report) and C034P1 which is some 5.6 km south of C9839SPR. Tracking this impact from dewatering south will therefore soon become difficult.

Site 10

Directly west of Mellaluka Springs as advised by Bravus in the GMMP review although they suggested not a priority at this time. DES consider that it is.

There are currently no Bandanna standpipe monitoring bores south of the mining lease.

There is a need in this area to:

- understand the relationship between the Bandanna Formation, Colinlea Sandstone and the Joe Joe and Tertiary
- Understand the impacts of local landholder use on water levels in this area and the challenges in unpacking which stress is causing impact

Therefore, the sooner baseline data is available from the proposed Bandanna Formation and Colinlea Sandstone bores in this area, the better. In the GMMP Review Bravus propose a monitoring bore in this area in the future but not until impacts are noted at the southern boundary of the mining lease. That proposal is not supported by DES as it is considered that there is a need for a monitoring bore at this location now.

Other Bores Proposed by Bravus in 31 January 2023 GMMP Review report.

Bravus propose 3 other bores (not discussed above) on their western lease boundary.

Two Colinlea Sandstone bores identified in the GMMP Review report as proposed bores 3 and 4 and one Bandanna Formation bore identified as proposed bore 7.

These sites were not requested by DES but are supported by DES as they will improve understanding on existing groundwater gradients from the west to the east and propagation of any drawdown impacts from mining towards the west.

Extract from Figure 3.1 from the January 2023 GMMP review report provided below.

DES Proposed Additional Monitoring bores

Colinlea Sandstone – D Seam – standpipe monitoring bores required

Site 1

On the western boundary of ML70441 in a location that won't be mined out. This should be located between C007P3 (RN158064) and Doongmabulla Springs. (In the January 2023 version of the GMMP review report Bravus propose new bore number 5 at this location. That is supported by DES).

Currently there are no Colinlea Sandstone monitoring bores (standpipe bores) west of the dewatering bores. In order to better understand the propagation of drawdown from the mine towards the Doongmabulla Springs there should be a Colinlea Sandstone monitoring bore on the western boundary of ML70441.

Site 2

Adjacent C19031VWP (RN190605), between Moses and Little Moses Springs.

There should be a monitoring bore (standpipe bore) in the area of C19031VWP (RN190605) as given the unreliability of the existing VWP bores there can be no guarantee that data from this VWP is representative of the Colinlea Sandstone. This bore is to be located between Moses and Little Moses springs, would provide a reliable head in the Colinlea in this area and also provide information on any propagation of drawdown from the mine to this area in the Colinlea. It would also provide valuable information for developing initial heads information in this western area of the groundwater model.

Site 3

Adjacent C558VWP (RN158596), 4.7 km north-west of the northern most current dewatering bore. (Bravus propose monitoring bore 1 at this location in the GMMP review. That is supported by DES)

There is a lack of Colinlea Sandstone monitoring bores adjacent the northern dewatering bores and immediately north of the dewatering bores. C19026SP (RN190091) and C006P3R (RN158063) are adjacent the southern dewatering bores. The closest monitoring bore north of these two monitoring bores is C011P3 (RN158069) some 11 km to the north-west. No impact from mining is being noted at C011P3 so existing propagation of drawdown north cannot currently be tracked.

Site 4

South of Carmichael River, approximately half-way between C840SP (RN158107) and C034P3 (RN158086) which are approximately 5.8 km apart.

There is a gap between C840SP (most southerly monitoring bore considered impacted, by Bravus in the 2022 annual monitoring report, based on observed water level trends) and C034P3 which is some 5.8 km south of C840SP. Tracking the impact of mining south will therefore also soon become difficult.

Site 5

Directly west of Mellaluka Springs as advised by Bravus in the GMMP review although they suggested not a priority at this time. DES consider that it is.

There are currently no Colinlea Sandstone monitoring bores south of the mining lease.

There is a need in this area to:

- understand the relationship between the Colinlea Sandstone and the Joe Joe and Tertiary
- Understand the impacts of local landholder use on water levels in this area and the challenges in unpacking which stress is causing impact

Therefore, the sooner baseline data is available from the proposed Colinlea Sandstone and Bandanna Formation bores in this area, the better. In the GMMP Review Bravus propose a monitoring bore in this area in the future but not until impacts are noted at the southern boundary of the mining lease. That proposal is not supported by DES as it is considered that there is a need for a monitoring bore at this location now.

Site 6

Adjacent C14012SP (RN158889) (approx. 3.6 km north of Little Moses Spring) as advised by Bravus in the GMMP review, proposed site 2. (This proposal is supported by DES)

This site would provide understanding of groundwater heads in the Colinlea Sandstone north and north-east of the Doongmabulla Springs allowing more accurate development of initial heads for modelling in this area. It would also provide information on any propagation of drawdown from the mine to this area in the Colinlea Sandstone.

Bandanna Formation – AB seam – standpipe monitoring bores required

Site 7

On the western boundary of ML70441 in a location that won't be mined out. This should be located between C008P2 (RN158067) and Doongmabulla Springs. (In the January 2023 version of the GMMP review report Bravus propose new bore number 8 at this location. That is supported by DES).

To the west of the dewatering bores there are only two Bandanna Formation monitoring bores. C008P2 (RN158067) which is located 1.4 km west of the dewatering bores and showing significant impacts from mining and bore C19018SP (RN190229) located 10km west of C008P2, adjacent Moses Springs. In order to better understand the propagation of drawdown from the mine towards the Doongmabulla Springs there should be a Bandanna Formation monitoring bore on the western boundary of ML70441.

Site 8

Adjacent C14012SP (RN158889) (approx. 3.6 km north of Little Moses Spring) as advised by Bravus in the GMMP review, proposed site 6. (This proposal is supported by DES)

This site would provide understanding of groundwater heads in the Bandanna Formation north and north-east of the Doongmabulla Springs allowing more accurate development of initial heads for modelling in this area. It would also provide information on any propagation of drawdown from the mine to this area in the Bandanna.

Site 9

South of Carmichael River, approx half-way between C9839SPR (RN158115) and C034P1 (RN158087) which are approximately 5.8 km apart.

In the Bandanna Formation there is a gap between C9839SPR (almost considered impacted by Bruvus in the 2022 annual groundwater monitoring report) and C034P1 which is some 5.6 km south of C9839SPR. Tracking this impact from dewatering south will therefore soon become difficult.

Site 10

Directly west of Mellaluka Springs as advised by Bravus in the GMMP review although they suggested not a priority at this time. DES consider that it is.

There are currently no Bandanna standpipe monitoring bores south of the mining lease.

There is a need in this area to:

- understand the relationship between the Bandanna Formation, Colinlea Sandstone and the Joe Joe and Tertiary
- Understand the impacts of local landholder use on water levels in this area and the challenges in unpacking which stress is causing impact

Therefore, the sooner baseline data is available from the proposed Bandanna Formation and Colinlea Sandstone bores in this area, the better. In the GMMP Review Bravus propose a monitoring bore in this area in the future but not until impacts are noted at the southern boundary of the mining lease. That proposal is not supported by DES as it is considered that there is a need for a monitoring bore at this location now.

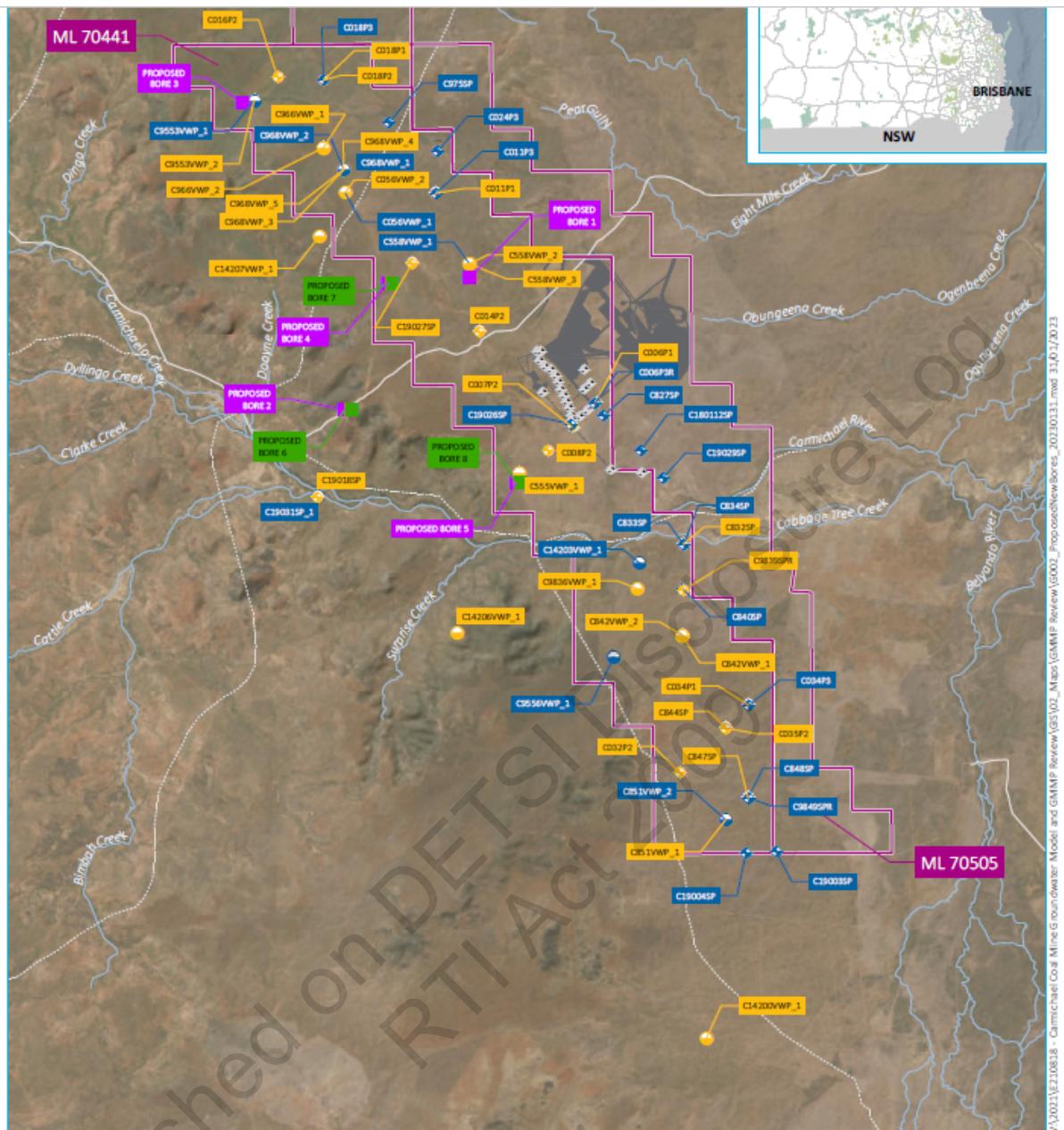
Other Bores Proposed by Bravus in 31 January 2023 GMMP Review report.

Bravus propose 3 other bores (not discussed above) on their western lease boundary.

Two Colinlea Sandstone bores identified in the GMMP Review report as proposed bores 3 and 4 and one Bandanna Formation bore identified as proposed bore 7.

These sites were not requested by DES but are supported by DES as they will improve understanding on existing groundwater gradients from the west to the east and propagation of any drawdown impacts from mining towards the west.

Extract from Figure 3.1 from the January 2023 GMMP review report provided below.



Source: EMM (2022); Brävar (2022); ESRI (2022); GA (2011)

- KEY**
- Proposed new monitoring bore - Bandanna Formation
 - Proposed new monitoring bore - Colindale Sandstone
 - Existing monitoring bore, Bandanna Formation
 - Existing monitoring bore, Colindale Sandstone
 - Existing VWP, Bandanna Formation
 - Existing VWP, Colindale Sandstone
 - Mining lease
 - Mining activity
 - Minor road
 - Vehicular track
 - Named watercourse
 - Dewatering bore

Proposed new monitoring bore locations

Carmichael Coal Mine
GMMP Review
Figure 3.1

Preliminary review of the Carmichael Coal Mine groundwater model report

Initial Heads

Bandanna Formation, Colinlea Sandstone and Joe Joe Formation

There is an area on the northern side of the Carmichael River encompassing the area of current mining, where in the pre mining period the lowest groundwater levels in the Bandanna Formation and Colinlea Sandstone have been noted as have some in the Joe Joe Formation.

In this current report Table 2.1 – Summary of the Conceptual Hydrogeological model, states:

- *A synform had been proposed during the SEIS phase, with a northeast to southwest fold axis that passes broadly through the centre of the site. The synform affects the Betts Creek Beds and Rewan Formation and the fold axis tends to align with a regional potentiometric 'low'.*
- *Two alternative conceptualisations have been recently proposed by EMM (EMM 2022a) as an alternative to the synform: local faulting or a permeable Joe Joe Group acting as an underdrain. The local fault (or higher permeable zone) is conceptualised to cut across the Bandanna, Colinlea and Joe Joe Group mainly within the lease area.*

The table also states, under the heading of local groundwater flow:

Colinlea Sandstone: Groundwater flow converges towards bore C006P3R and is likely influenced by the local faulting/high permeable zone previously proposed.

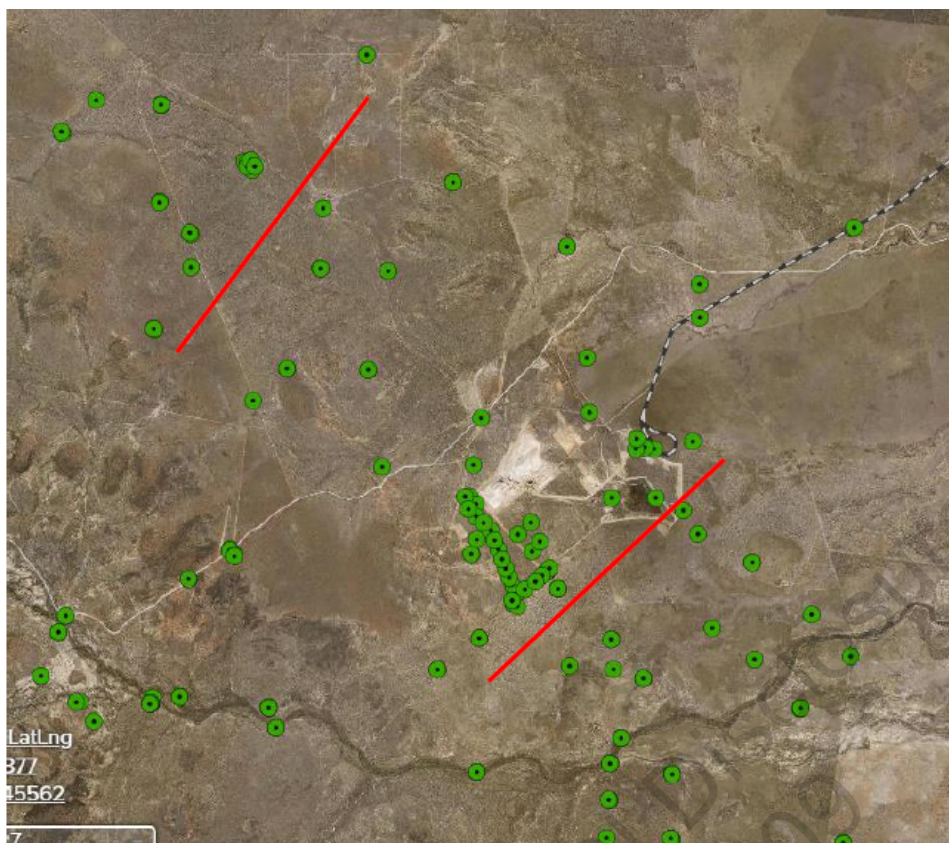
The synform theory is rejected as it does not account for the discharge of groundwater that would be required to cause these groundwater lows.

Whilst EMM have developed alternative conceptualisations they have not incorporated any of these potential discharge processes into the numerical groundwater model.

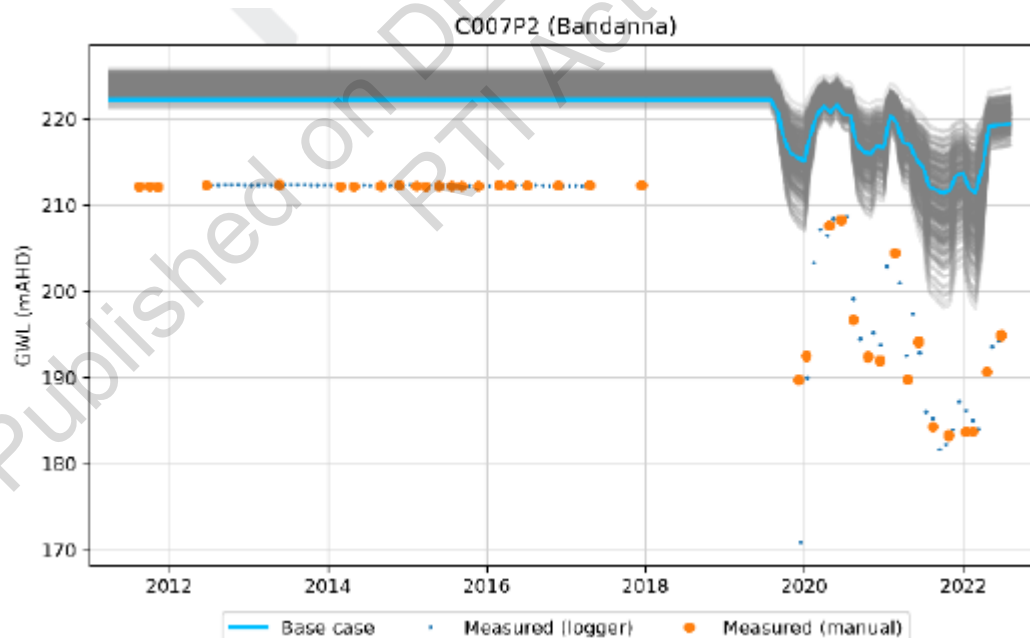
It appears that subsequently the model is unable to replicate these groundwater lows in this area in the pre mining period (pre 2019).

The model simulated initial heads for the calibration hydrographs as provided in Appendix C are therefore generally about 8 to 12 m higher than observed water levels in the Bandanna Formation and Colinlea Sandstone in this area. There are few Joe Joe bores in this area but in two bores located north-east of the current mining the initial heads are 7 m higher than observed water levels.

This is a poor representation of pre mining conditions and not a strong basis for model calibration and prediction in an area where dewatering conditions can provide excellent data for model calibration.

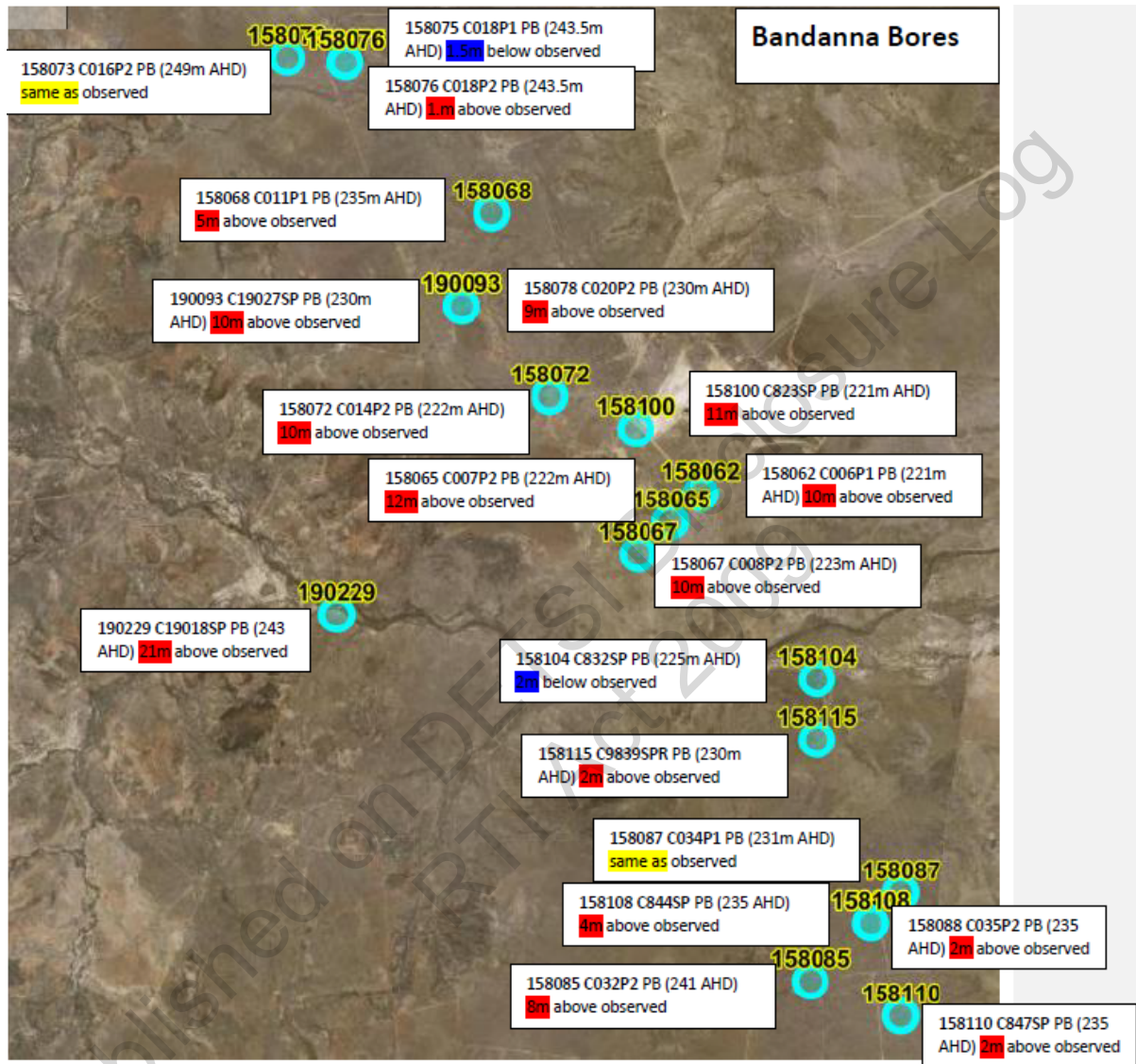


Red lines denote approximate area where model is predicting much higher initial heads than observed water levels in Bandanna, Colinlea and a couple of Joe Joe bores.



C007P2 - Example of an Appendix C calibration hydrograph where modelled initial heads are approx. 12 m higher than observed.

In each geologic unit the calibration hydrographs identified as representing that unit in Appendix C have been examined and an assessment of the variation between modelled base case initial head and observed water level made and then plotted on a map to understand spatial variation of these differences. An example is provided below for the Bandanna Formation. Similar figures are available in Appendix A for all geologic units except the Moolayember.



PB – Predicted Base case initial head

Initial Heads Alluvium

Appendix C contains 5 alluvial bores located in the Carmichael River alluvium. The base case initial heads for these five bores are between 6 and 12 m higher than observed water levels in these bores. This is a poor representation of the alluvial aquifer.

Modelled steady state contours are provided in the report for the Clematis Sandstone, AB Coal Seam and D Coal Seam only. It is not clear how the initial heads for the alluvium was determined.

Given this poor match between simulated and observed heads it is not clear how recharge and discharge processes in the alluvium will be impacted in the model, including its connectivity with Carmichael River surface flows, and how if at all the model can be used to provide commentary on environmental values associated with the river and the alluvium.

There is also concern about 5 other bores in Appendix C which are identified as being in the alluvium and may have been used in the model calibration. These bores appear to be in clayey material to the north of the Carmichael River and if they are in an alluvial aquifer it seems likely to be very poorly connected to the Carmichael River alluvium. Of these 5 bores in question 4 are always dry. It needs to be understood if these 5 bores have been used in the calibration process, if so that seems questionable.

Initial heads in Base Case Tertiary and Weathered Zone

Appendix C contains 5 bores identified as being in the Tertiary sediments only. The 4 northern bores have Base Case initial heads of between 3 and 12 m above observed water levels. The fifth bore, just south of Mellaluka Springs has an initial head 13 m lower than the observed water levels.

It is not clear how the initial heads were determined for the Tertiary sediments and it is not clear how those bores in Appendix C identified as monitoring the Tertiary and Joe Joe (composite) are used in the calibration process, i.e. representing which layer?

In the Weathered Zone, Appendix C contains 8 bores identified as being in the Weathered Zone. Three of these bores are always dry and it is not clear if they have been used for calibration purposes. Of the remaining 5 bores the model simulated initial heads for the Base Case are between 7 and 11 m higher than observed water levels. This would appear a poor match.

Initial Heads other geologic units/ other areas

Clematis- There is a generally fair to good match between initial heads and observed water levels.

Dunda Beds – There is a good match between initial heads and observed water levels.

Rewan Formation – There is generally a fair to good match in the upper Rewan between initial heads and observed water levels, particularly good near the Doongmabulla Springs. It is accepted that in parts of the Rewan, connectivity is poor and modelling of that connectivity can be challenging.

Joe Joe – Outside the area north of the river, previously discussed, the match between simulated initial heads and observed water levels is good.

Bandanna – outside the area north of the river, previously discussed, the match between simulated initial heads and observed water levels is fair to good. The exception is adjacent the Doongmabulla Springs and bore RN190229, C19018SP.

To develop steady state contours the bioregional assessment contours have been used (at DES' suggestion) to obtain regional water levels and in particular those off to the west. This appears to have resulted in an over estimation of initial heads at 190229, near Moses springs of 21 m.

The regional Bioregional Assessment contours in the Bandanna are primarily driven in this area by a drill stem test in coal seam gas exploration hole, Shoemaker No.1 (located 3.5 km north-west of 190229). It had an estimated head in the Bandanna of 245 m AHD. Given that the water level in an open monitoring bore (190229) is likely to be more accurate than that of a drill stem test, in a bore not primarily constructed to obtain water levels, it is considered that more weighting should be given to the water level in 190229 than Shoemaker No.1.

Colinlea- outside the area north of the river, previously discussed, the match between simulated initial heads and observed water levels is fair to good.

Ability to model dewatering impacts

The 2022 Annual Groundwater Monitoring report identified the following bores as being impacted from dewatering based on the observed water level trends in the bores.

Based on the calibration hydrographs provided in Appendix C a comparison of observed vs modelled water levels (Base Case) is provided below.

In summary the model base case may be slightly under predicting drawdown in bores in the AB seam, C Seam and D seam, close to the dewatering bores.

It also appears to have some difficulty predicting impacts in bores which are not directly accessing the seams and may be in less permeable interburden above or below the seams. In these instances (eg C006P1 and C834SP) there is evidence to suggest the model is slightly over estimating impacts.

Further from the dewatering the model appears to be predicting similar of slightly higher impacts then observed.

It is also noted that the base case simulated drawdowns are greater in C008P2 than in C007P2 when C008P2 is well west of C007P2 (adjacent a dewatering bore).

Bandanna

Bore Number	RN	Observed max DD (m)	Base case max DD	Simulated Initial head (Base Case) above observed (m)	Comments
C006P1	158062	8	19	10	Located in interburden above C seam. Has possibly led to underpredicted dd
C007P2	158065	30	10	10	AB Seam
C008P2	158067	25	20	10	AB Seam. Problem here in that more drawdown is predicted in the bore further away from dewatering than C007P2.
C823SP	158100	27	16	11	C seam

C832SP	158104	3	5	-2	C seam
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Colinlea

Bore Number	RN	Observed max DD (m)	Base case max DD	Simulated Initial head above observed (m)	Comments
C006P3R	158063	31	22	8	D Seam
C180112SP	158093	49	21	1	Sand below D seam
C827SP	158102	37	39	9	E Seam
C833SP	158105	5	5	-1	D Seam. Model not picking up differences in 833 and 834, different units different dd but model says the same.
C834SP	158106	2.5	5	0	Clay and siltstone below D seam
C840SP	158107	2	3.5	2	Sand below D seam
C19026SP	190091				Not used in calibration, replaces C007P3
C19029SP	190604				Not used in calibration, replaces C180114SP

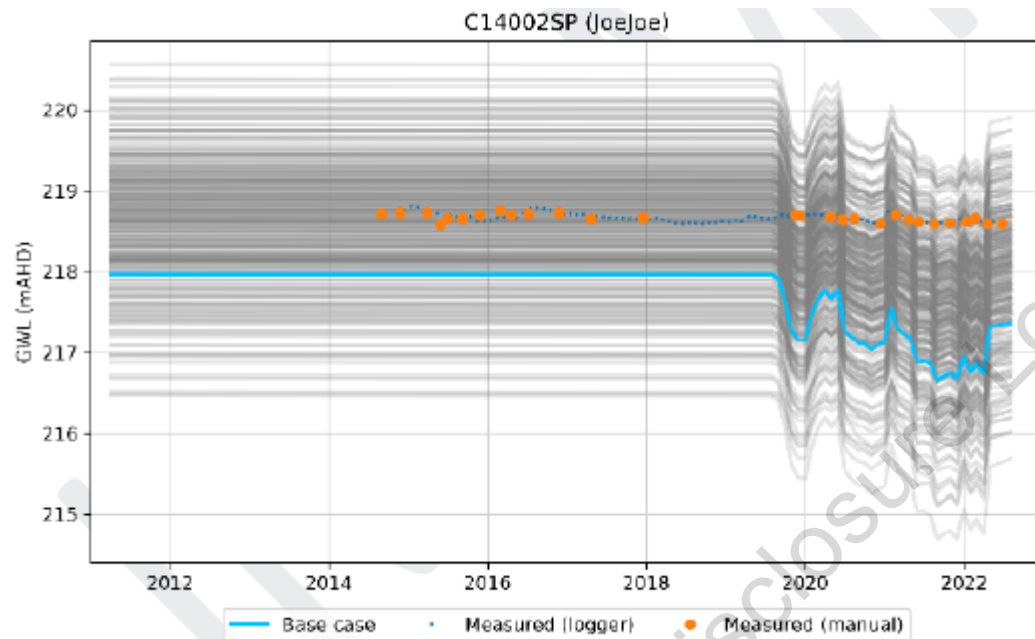
Overpredicting drawdown extent and drawdown

At the southern end of the lease there are predicted drawdowns in the Colinlea from dewatering when there are none observed (C19004SP and C19003SP). There are also predicted drawdowns in the Joe Joe, caused by dewatering, in a number of places in bores (south lease area and down towards Mellaluka Springs) when none had previously been considered to be occurring.

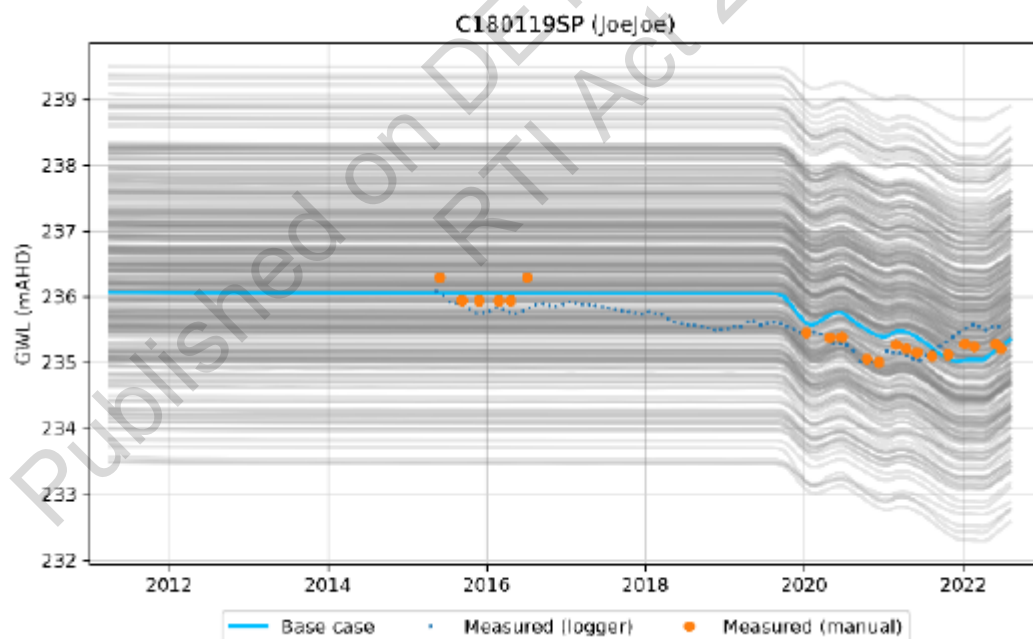
Part of the problem may be that there is some drawdown in some Joe Joe bores to the south caused by local landholder use and the model does not incorporate landholder use so it is trying to replicate the drawdown using dewatering impacts. Perhaps this problem could be addressed by incorporating some landholder use.

The other concern here is the significant increase in predicted impacts in a number of formations including the Joe Joe. In determination of previous groundwater level thresholds in Joe Joe bores adjacent Mellaluka Springs the maximum predicted drawdown had been determined to be less than 1 m. In the new model open cut only scenario, Appendix A in the GMMP Review report, the

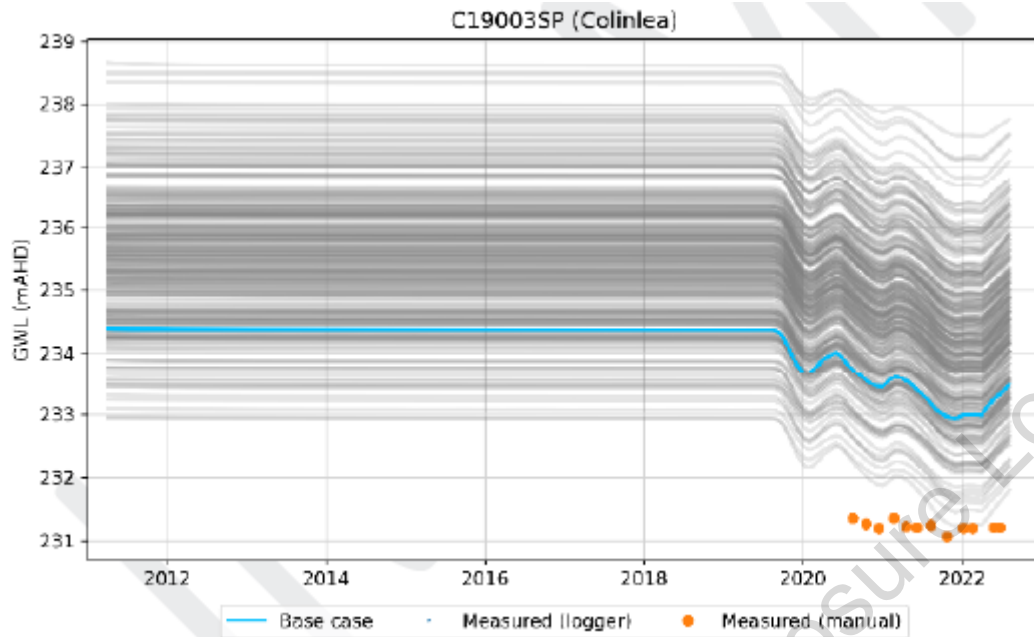
maximum predicted drawdown is now 60 to 80 m in these same Joe Joe bores. Is that realistic or has the model been unduly influence by not including landowner water use in this southern area.



RN165366 Joe Joe bore located south-east of current mining approx. 5 km from nearest dewatering bore. Predicted drawdown from mining when none occurring.



RN158096 Joe Joe bore located 21 km south of the Carmichael River. Some oscillation of observed groundwater levels is occurring and the model is simulating impacts from mining.



RN190228 Colinlea bore located on southern boundary of lease, 15 km south of Carmichael River. No apparent decline in observed groundwater levels and model is simulating impacts from mining.

Calibration Targets

Section 4.1.1 of the draft model report states:

A total of 11,443 history-matching targets were employed. These were subdivided into the following groups:

- *239 hydraulic head targets, grouped by HSU;*
- *11,202 head-change targets, grouped by HSU; and*
- *2 flux targets.*

It is further stated that the weights of the hydraulic head targets were increased to double the relative computational effort towards matching absolute groundwater levels.

However, the number of heads targets vs head change targets is very low and it is not clear if the calibration process may be overly biased towards head change rather than a mixture of head change and absolute heads.

Dewatering Volumes used in modelling

Section 3.5.5 Mining Activities states:

i Production bores

The MODFLOW well (WEL) package is employed to simulate groundwater abstraction from mine dewatering bores. Measured groundwater abstraction for each bore is incorporated in the monthly stress periods in the history-matching period from August 2019 to March 2022 (Table 3.2).

On a number of occasions Bravus and EMM have been asked how they will attribute dewatering volumes to each layer in the model given the dewatering bores typically take water from multiple model layers. DES had been advised that this process would be explained in the model report. It does not appear to have been.

Uncertainty Analysis Presentation of Results

Appendix D provides hydrographs of predicted long term water levels for the Open Cut only scenario.

In the DSC springs the maximum predicted drawdown is about 0.10 m.

The presentation provided by Bravus on 31 January 2023 demonstrated that at an assortment of the DSC springs, in 0% of the predicted model runs the drawdown at these springs exceeded 0.2 m.

However, in section 5.1.1 of the model report, the subject of assessing the likelihood of drawdown, is discussed. Table 5.1, reproduced below provides explanation of the approach.

Table 5.1 Combined numeric, narrative, and visual approach for assessing the likelihood of drawdown

Percentile band (outcomes ranked from small to large)	Colour code	
<P10		It is very unlikely that drawdown exceeds the threshold
P10 to P33		It is unlikely that drawdown exceeds the threshold
P33 to P67		It is as likely as not the drawdown exceeds the threshold
P67 to P90		It is likely that drawdown exceeds the threshold
>P90		It is very likely that drawdown exceeds the threshold

The model report states:

the approach is based on Table 2 of the IESC guidance note on uncertainty analysis (Middlemis and Peeters 2018).

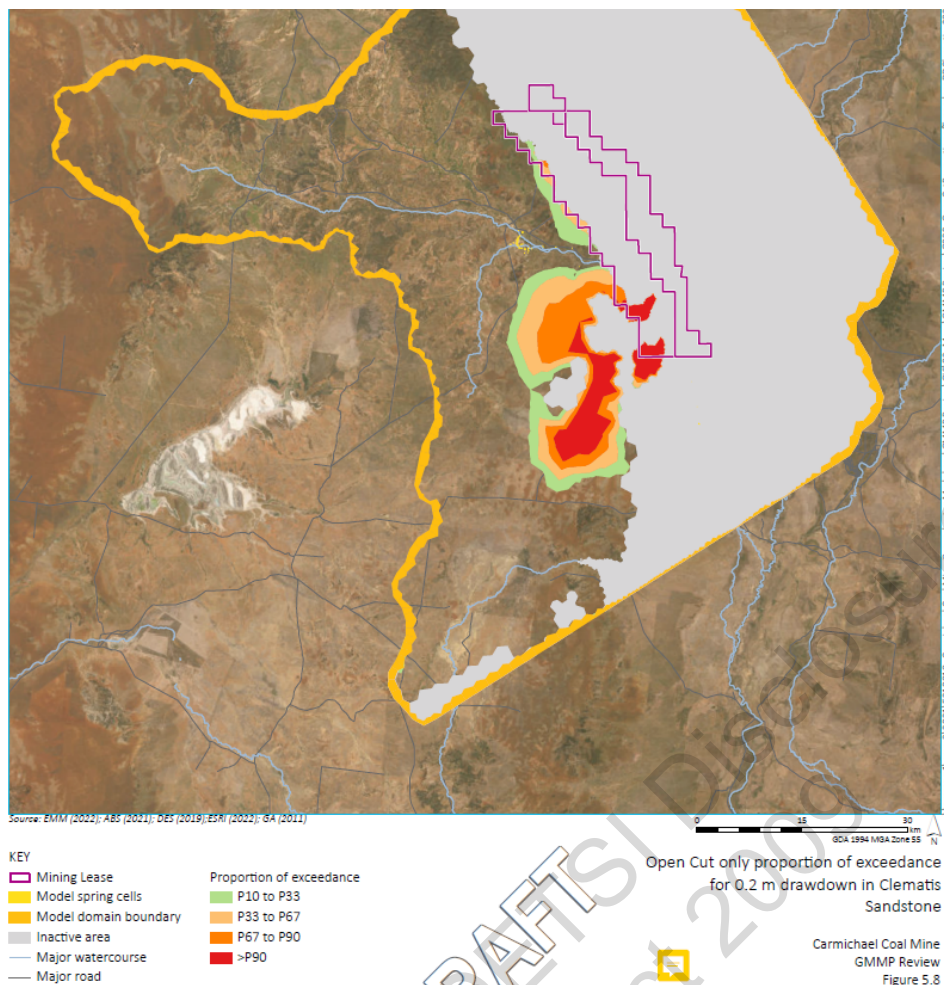
In Figure 5.8, reproduced below, the proportion of exceedance of 0.2 m drawdown (open cut only scenario) is mapped for the P10 to >P90 areas. Less than P10 is not mapped and it is not clear if everywhere else is inferred to be less than P10 or how that is interpreted.

As a result, the model report then states:

Figure 5.8 shows the contour intervals for the likelihood of exceedance of the 0.2 m drawdown threshold in the Clematis Sandstone for the open cut only scenario. The 'very likely' region is in the south to southwest of the mine lease and away from sensitive receivers. All DSC springs fall within the 'very unlikely' category, meaning that the springs are predicted to be under little risk of experiencing drawdown in breached of the drawdown threshold.

This may just be a different way of presenting the same outcomes but it can be somewhat confusing or misleading to firstly see that none of the uncertainty runs are predicted to exceed a drawdown of 0.2m but then in the text of the report it says that it is very unlikely that drawdown will exceed 0.2m at the springs.

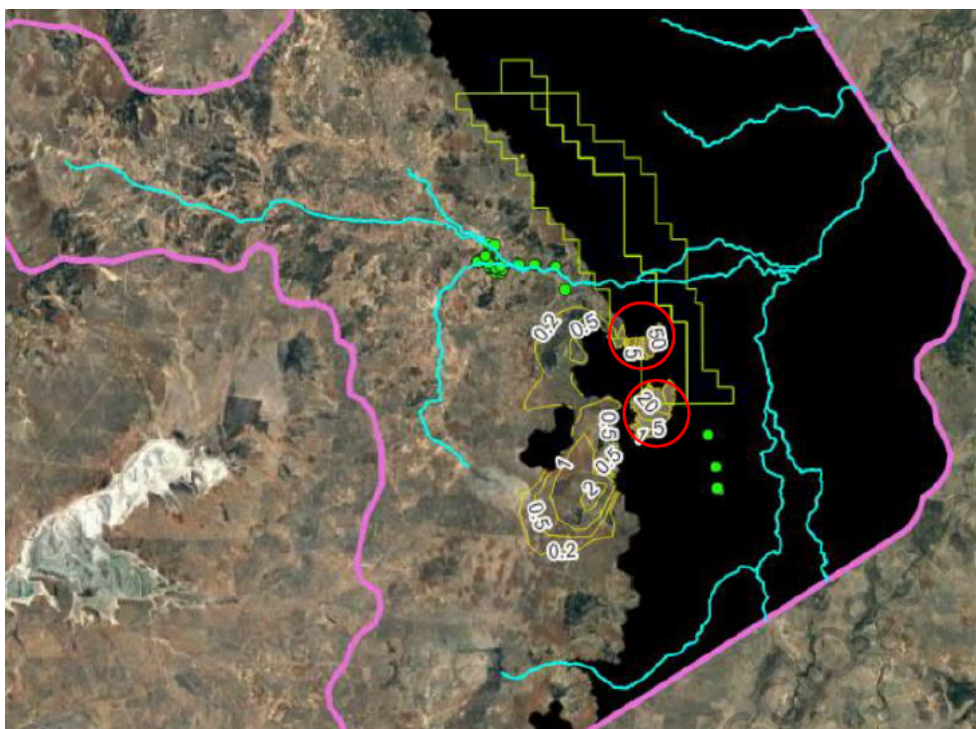
Further advice should be sought on this matter and possibly clarification of how the two pieces of information should be interpreted.



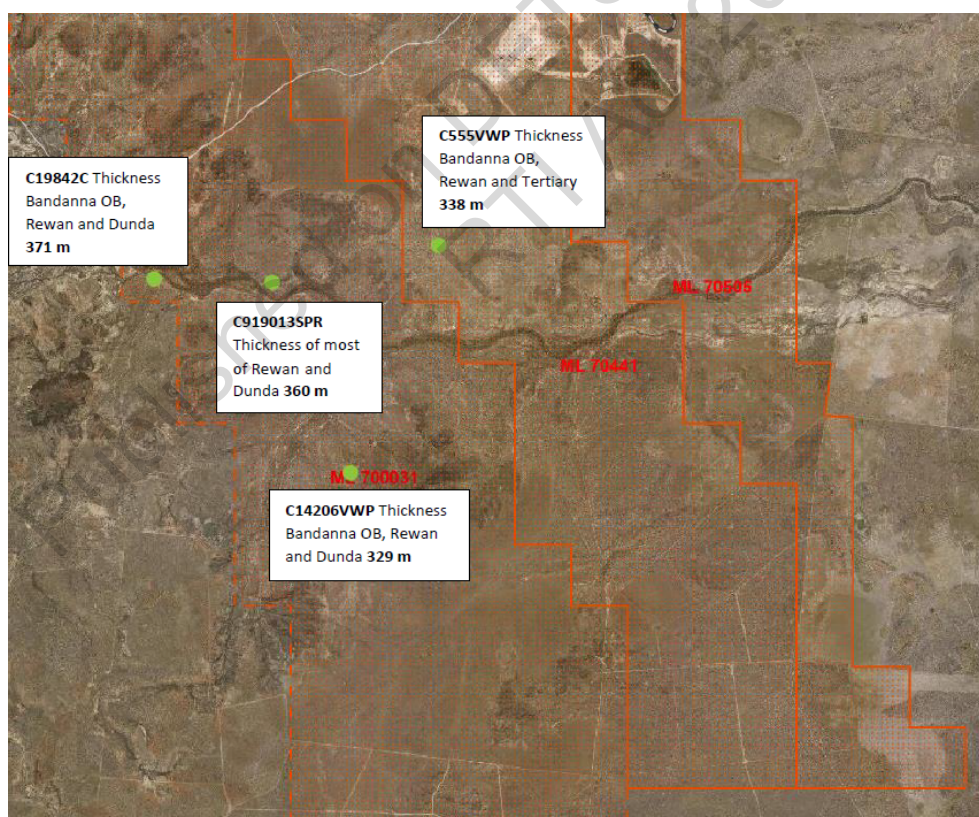
Geology, extent of Clematis and Dunda Beds

There is an area on the south-western edge of the mining lease where the extent of the Clematis Sandstone has been reinterpreted based on the Titus modelled geological layers. Some interpretation has occurred when using the geological layers to update the numerical model layers.

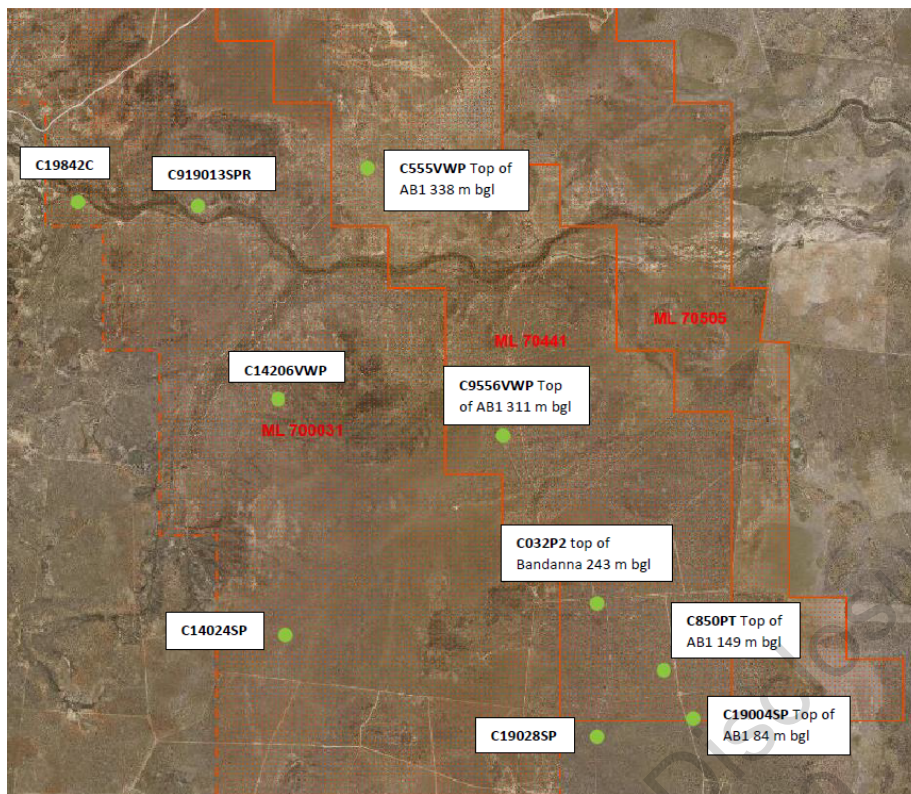
As a result, there are some narrow Clematis extents that are now predicted to intrude into the mining area, where previously they had not. This Clematis mapping was explored further.



The orange circles represent the areas of Clematis Sandstone which are now mapped and modelled as extending into and adjacent the lease area



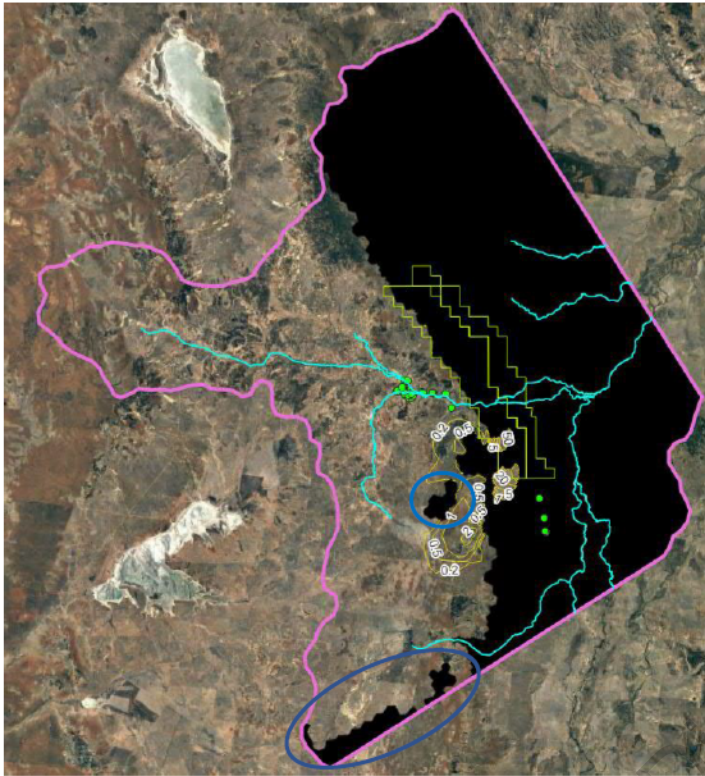
Determining average thickness of the Bandanna overburden (above AB seam) Rewan and Dunda Beds in the area, which is some 330 m in this area.



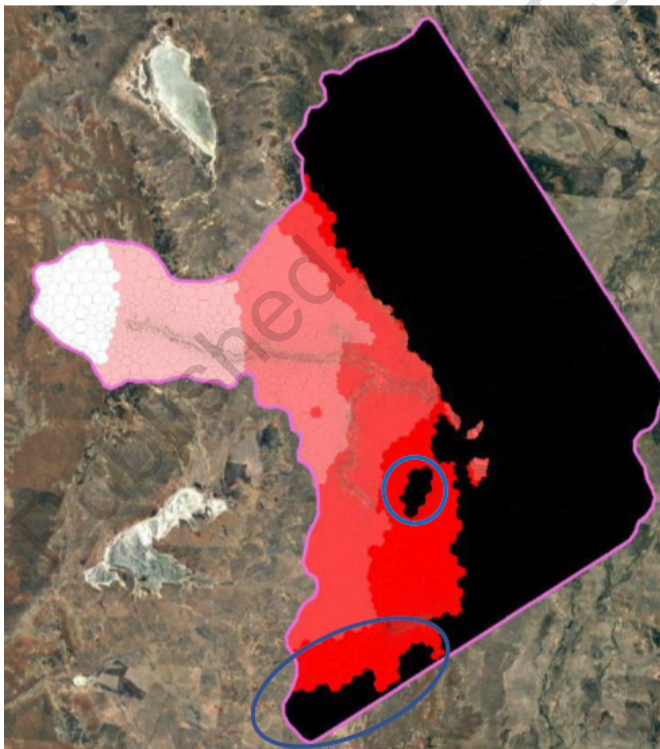
Determining depth to top of AB Seam in the south-western lease area

Based on the average depth of cover above the AB seam and the depth to the AB seam in this area, there appears to be no evidence of Clematis sandstone jutting out into the lease area as has been mapped. That needs review based on actual data.

Other areas of concern with Clematis and Dunda mapping



Clematis



Dunda

The circled areas show areas of apparent 'holes' in the Clematis and Dunda which are not supported by existing mapping available in the area.

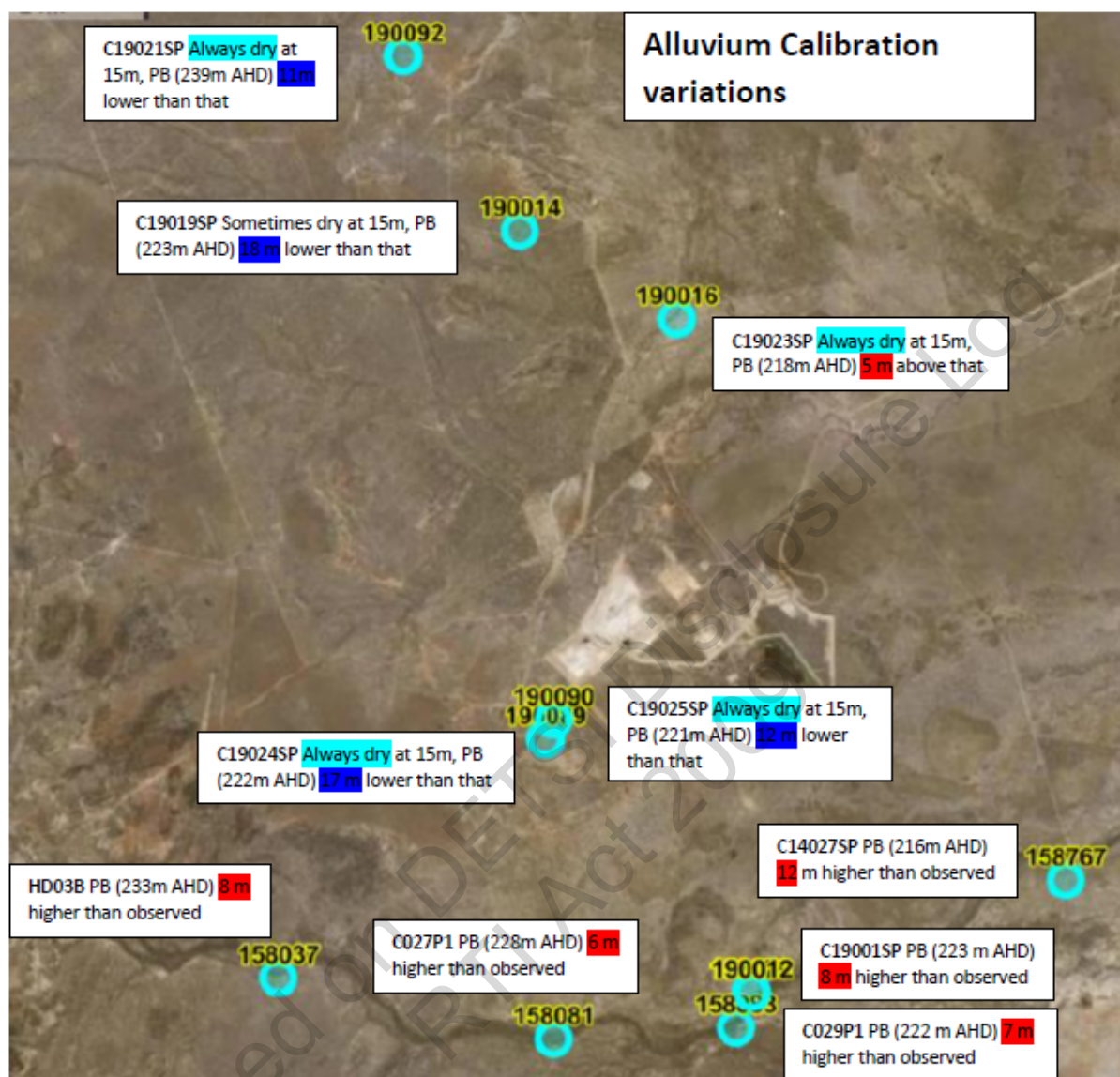
Section 7, Summary and recommendations from the model report states the following:

As noted by Murray (2022), tying in the local Rewan Research model to the Bioregional assessment model highlighted some very significant mismatches and worrying errors. Murray recommended that a full review of the broader Bio-regional assessment model is warranted.

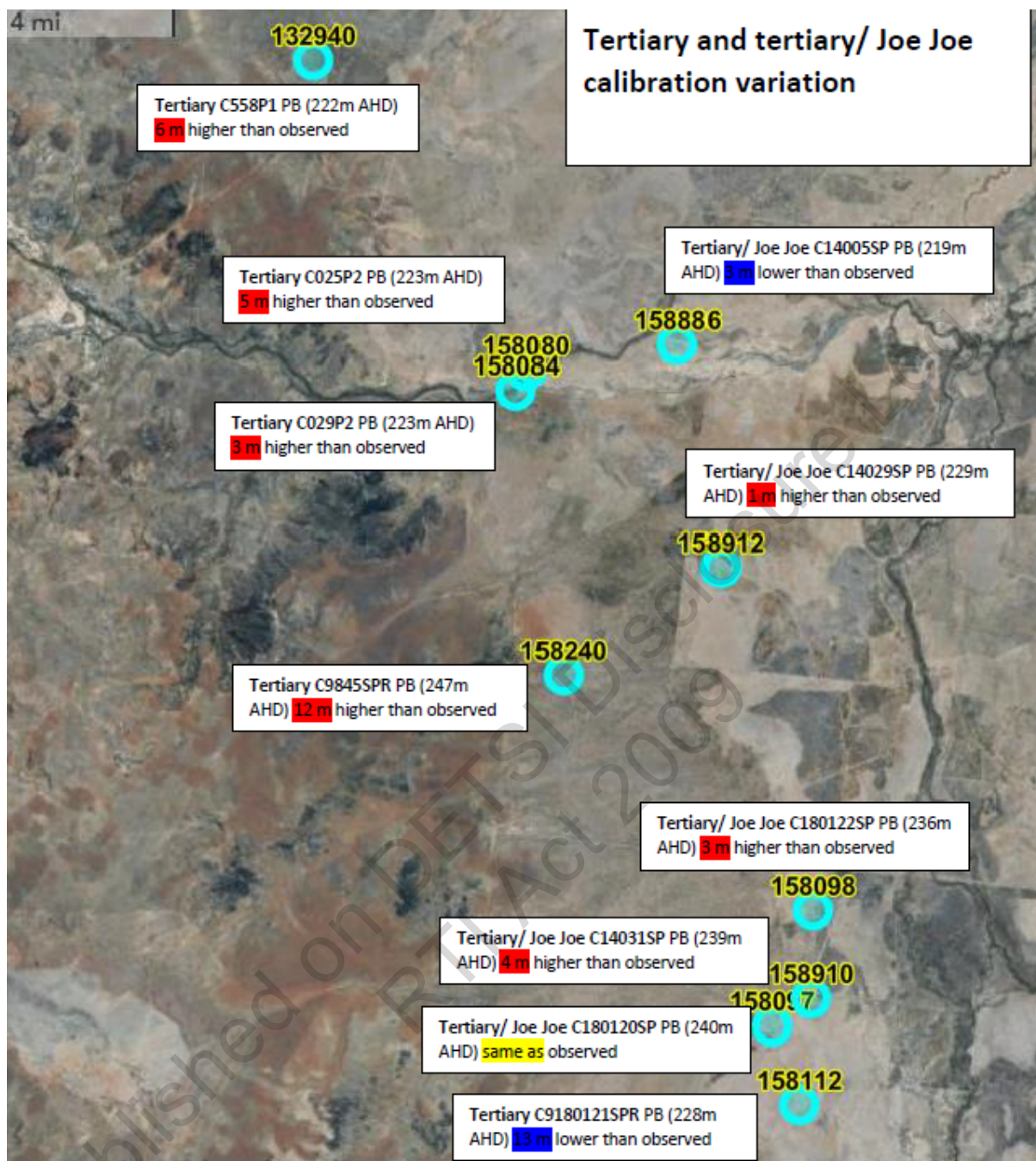
This appears to be the problem with the holes identified in the maps above. It is noted that there is now a lot of additional data in this area including from CSG holes and it is considered that a more realistic representation of the Clematis extent could be provided in the model area than has been presented.

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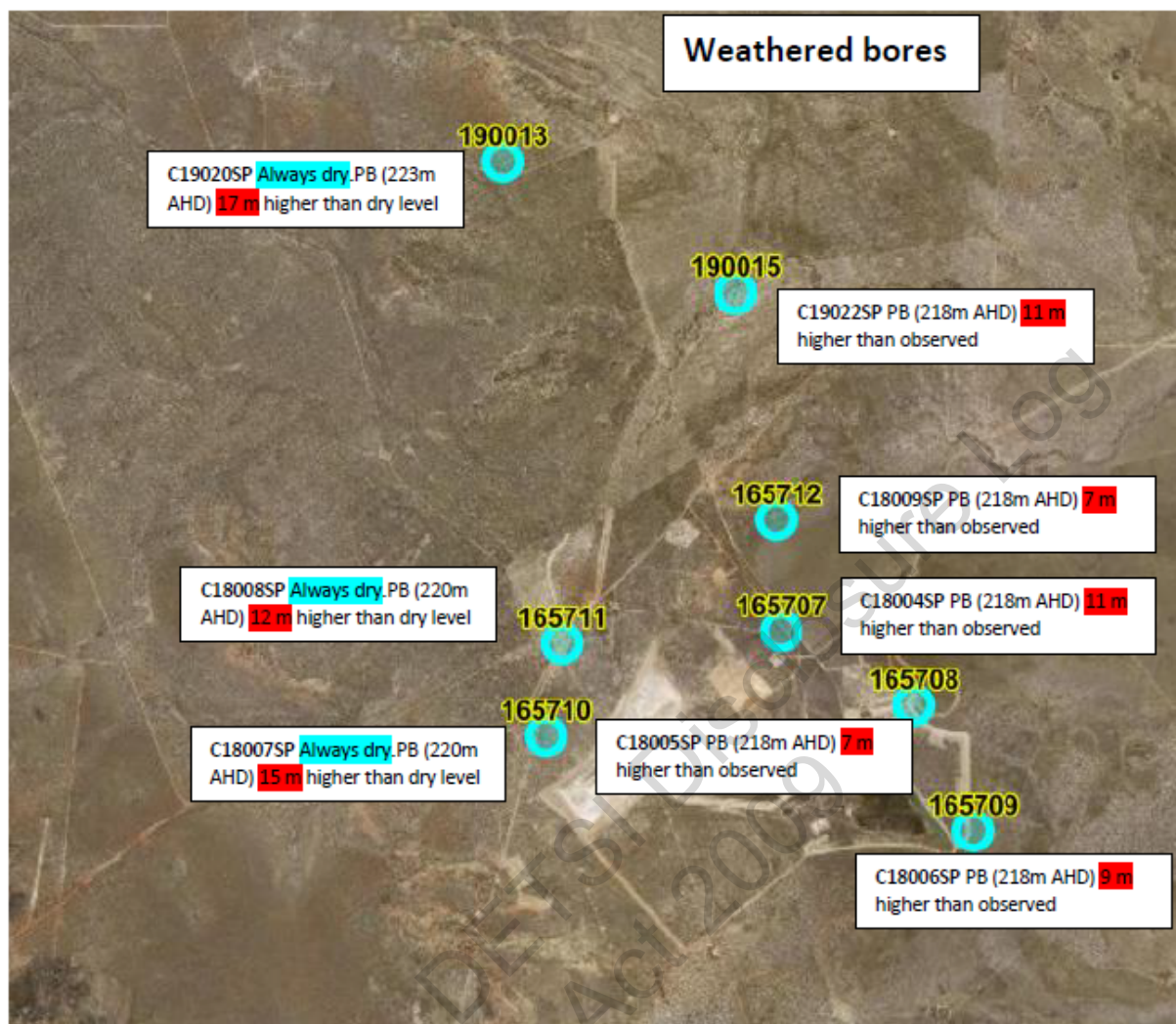
Appendix A

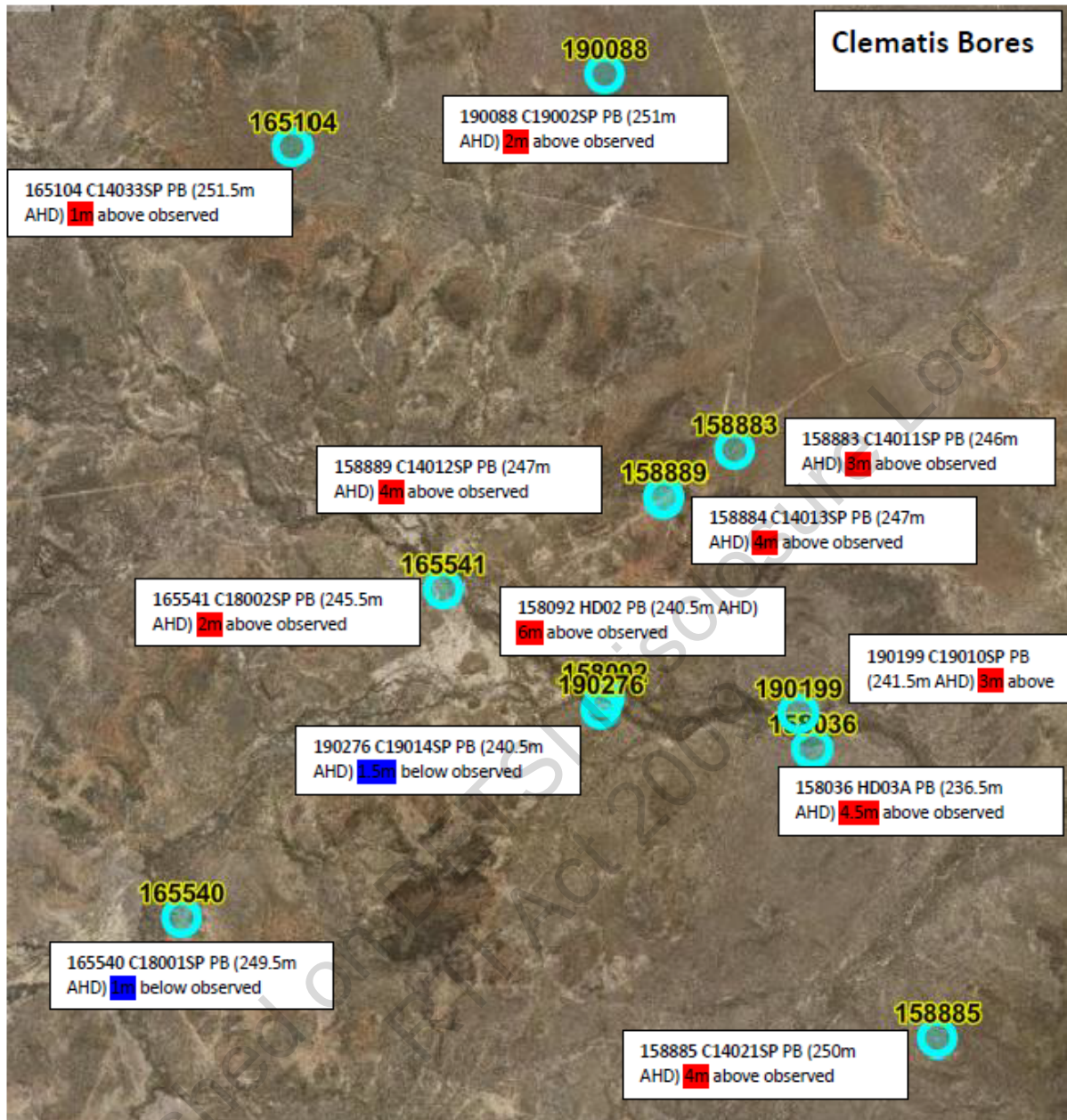


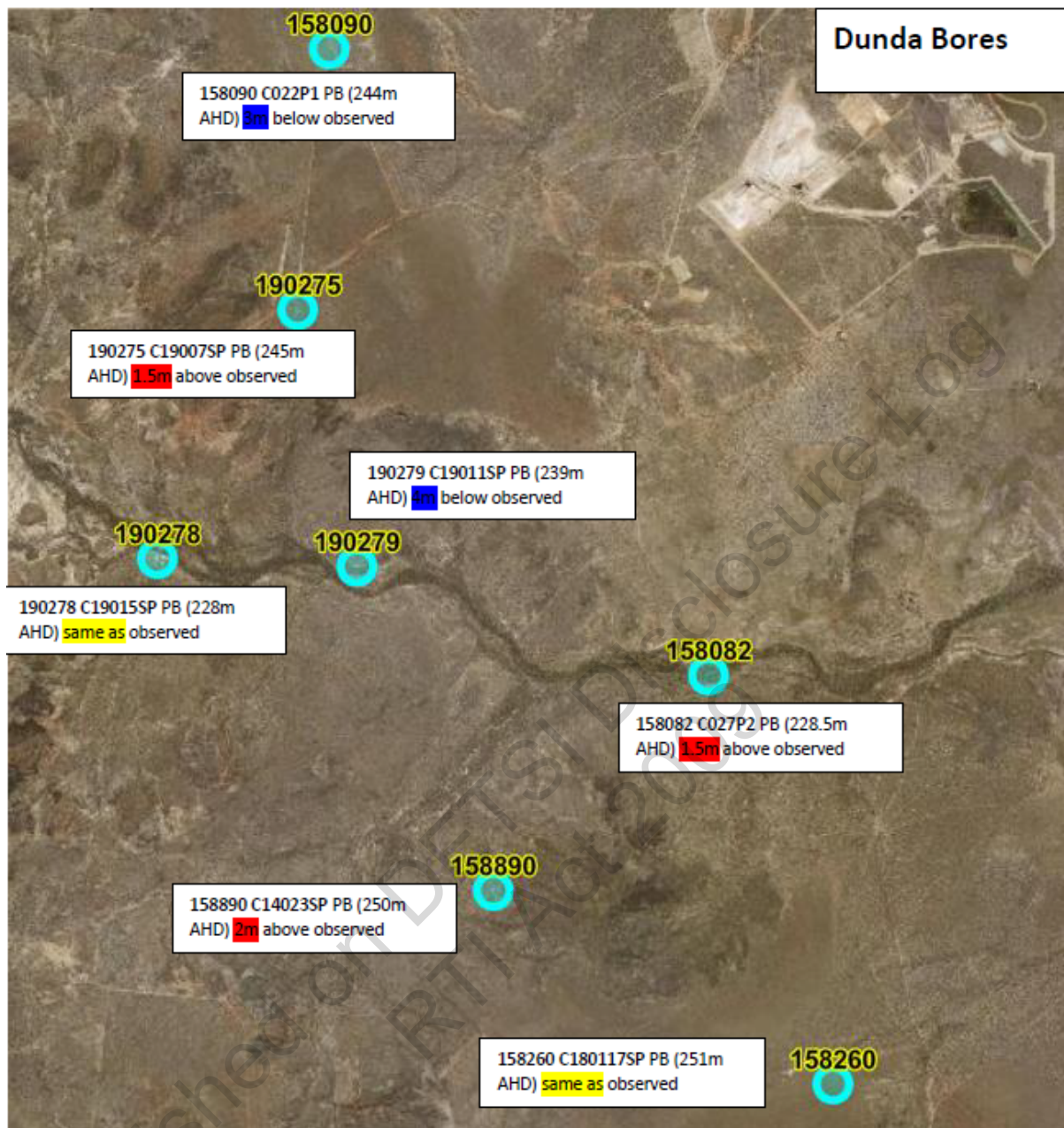
PB – Predicted Base Case initial head

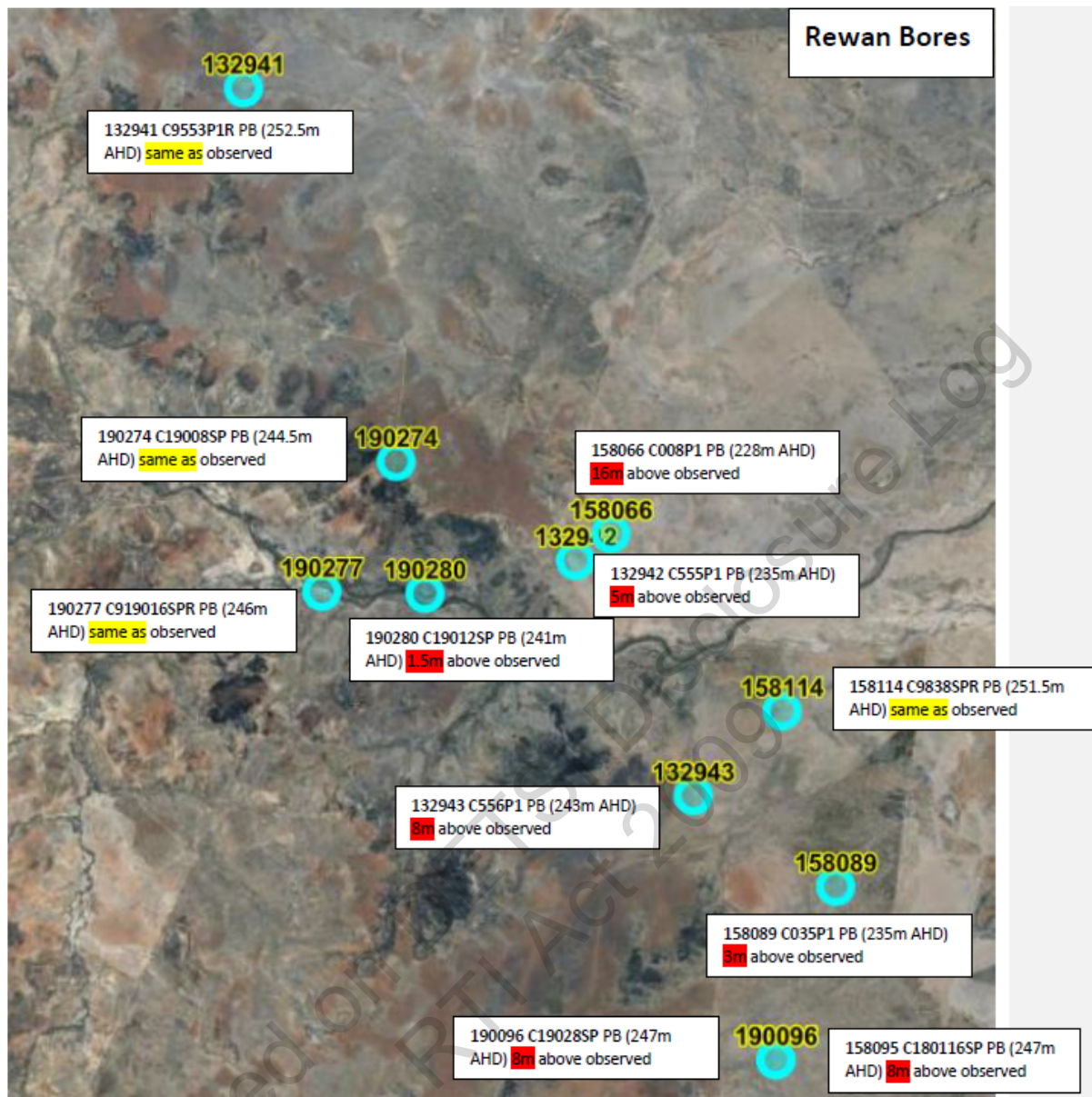


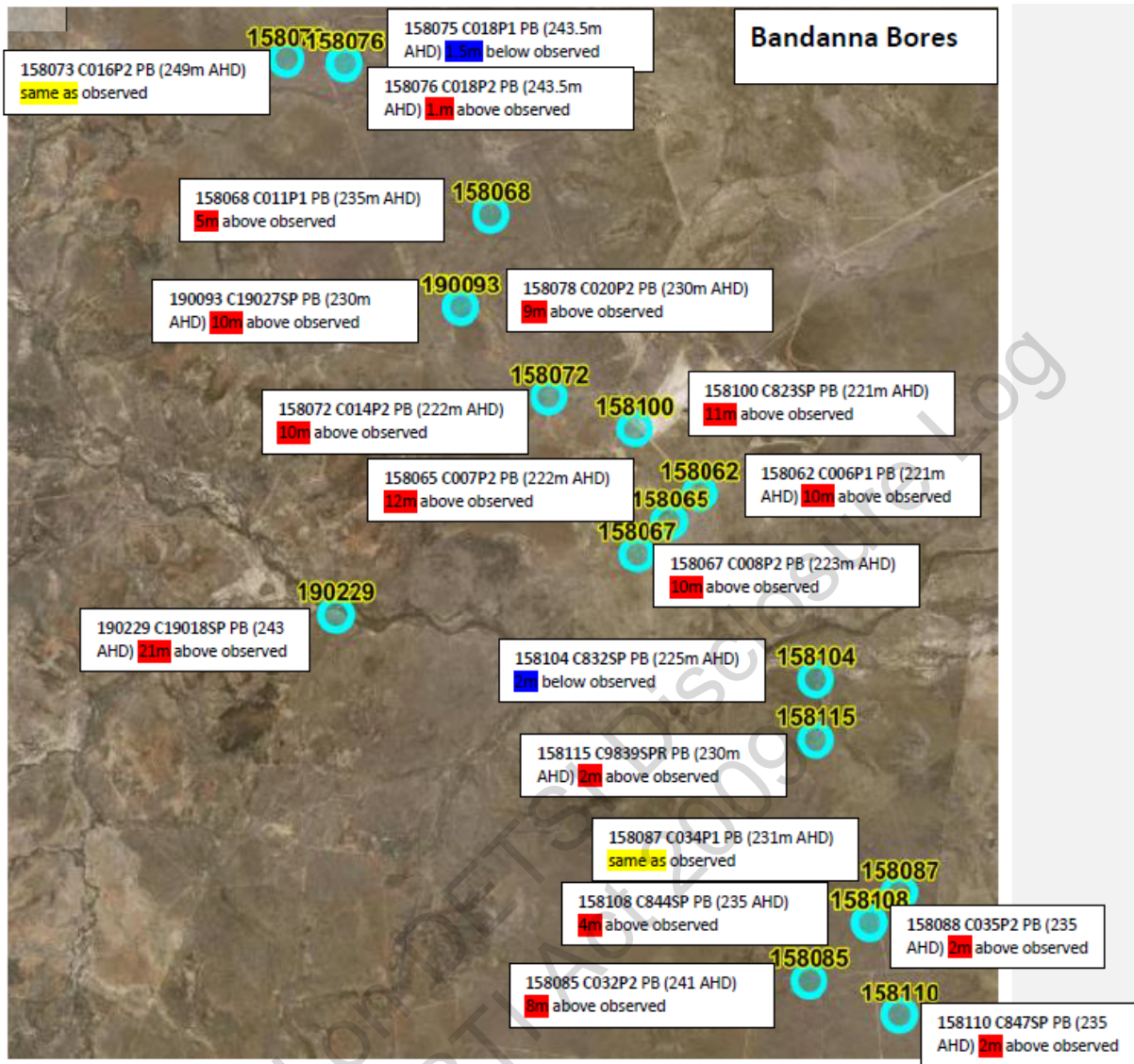
Two sets of bores, those representing the Tertiary Sediments and those accessing both Tertiary and Joe Joe described as composite in Appendix C and not clear what layer they represent in the model

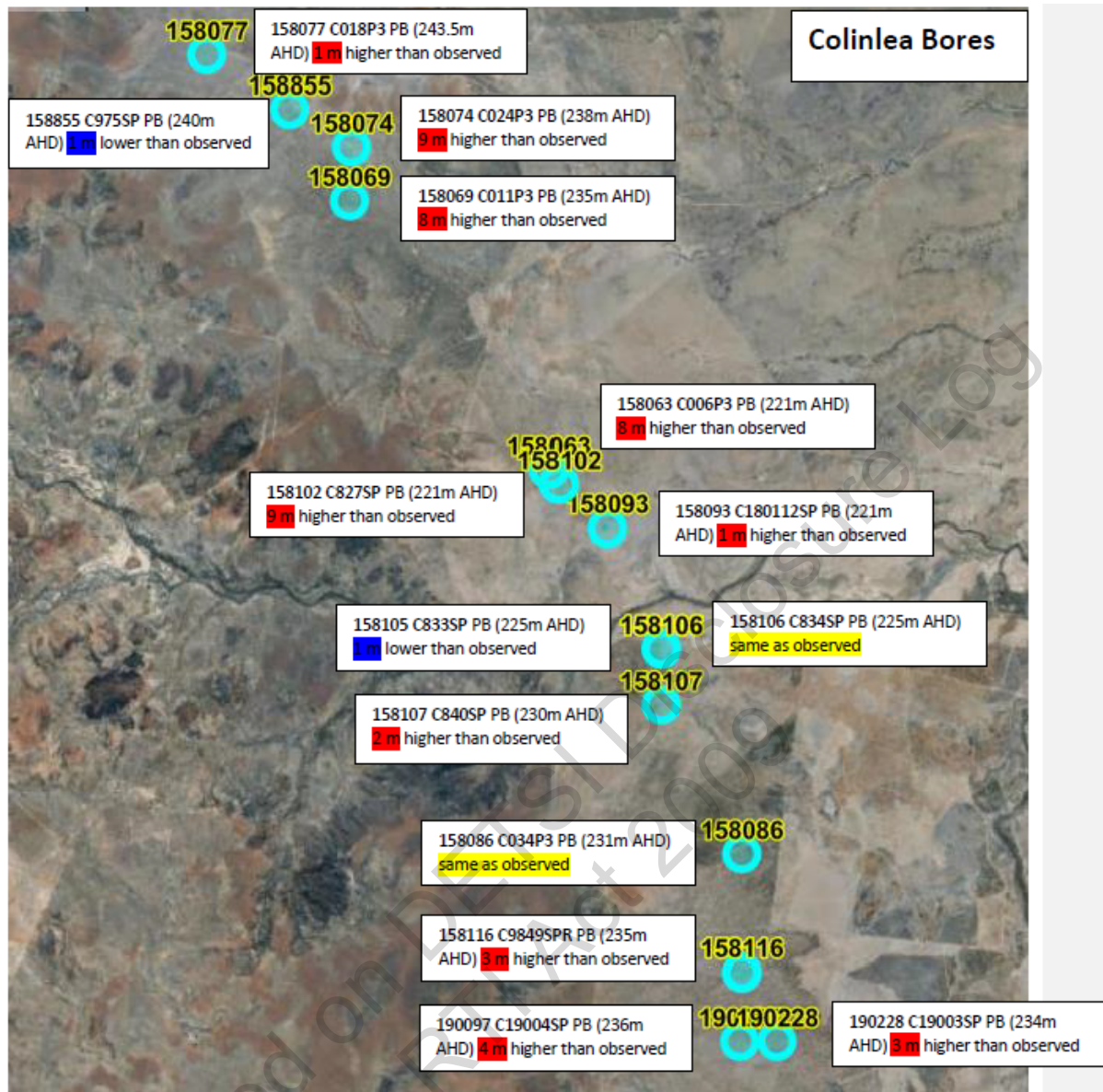




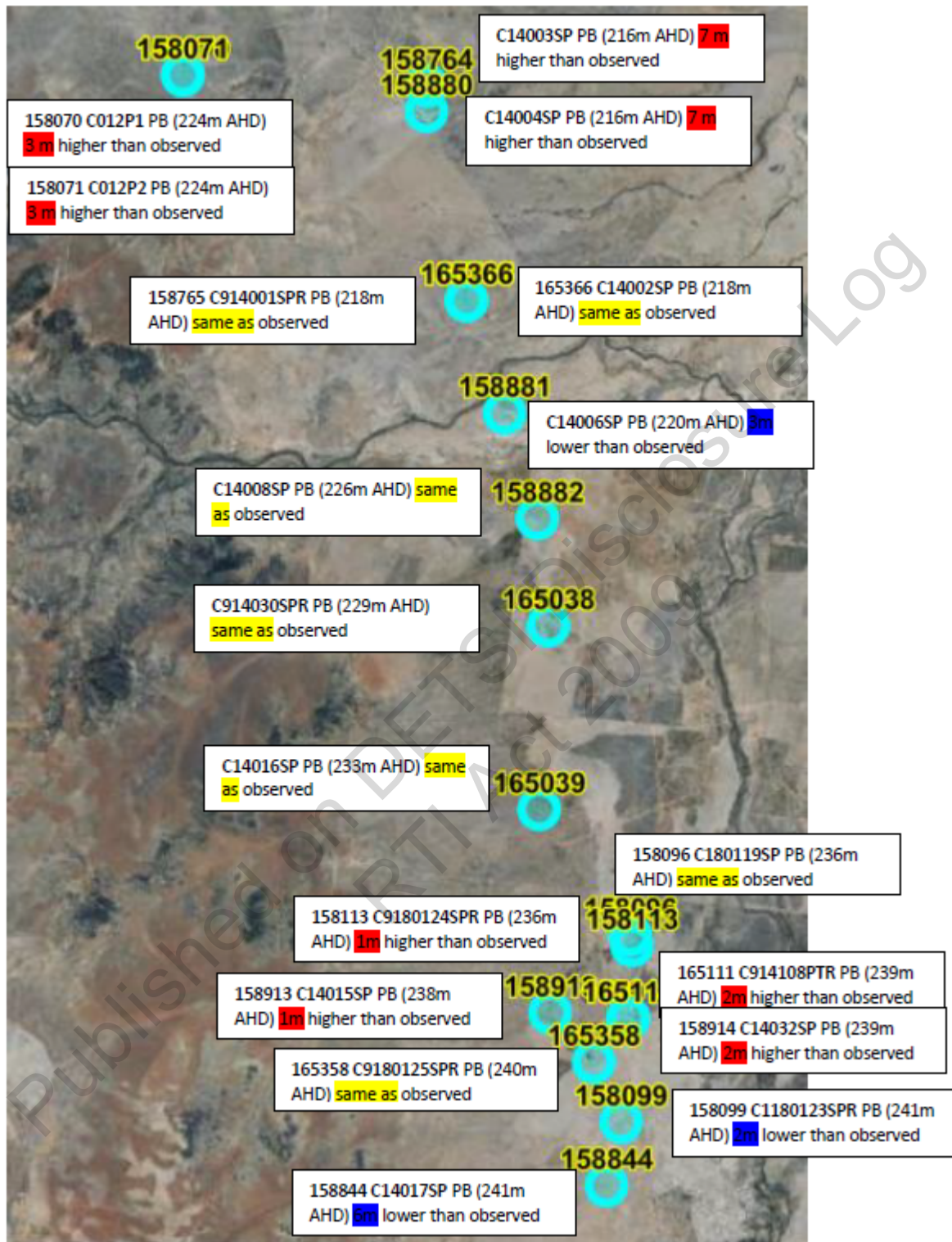








Joe Joe Bores



CSIRO/GA Questions

Model Report

1. Does the uncertainty analysis presented in the GW Review report meet the IESC guidelines and will it provide an acceptable/realistic range of potential impacts?
2. Is the methodology used to model the impacts of long wall mining under the SEIS B scenario adequate and appropriate, particularly with respect to prediction of impacts to the Doongmabulla Springs Complex?
3. Has the use of pilot points resulted in a more accurate representation of parameters instead of using one parameter value per layer?
4. Is the model cell size of 500m in the mining areas appropriate especially with respect to identifying longterm impacts from residual voids post mining?
5. Do the initial heads determined in the history matching process adequately represent the observed groundwater heads and groundwater system. In particular:
 - Does the model represent the pre mining groundwater lows observed north of the Carmichael River in the Bandanna Formation, Colinlea Sandstone and Joe Joe formation? Does the model incorporate findings from the conceptualisation?
 - Do the initial heads and simulated groundwater levels in the Carmichael River alluvium adequately represent that aquifer and if not, how might this affect the understanding of surface water-groundwater interaction? Has the use of dry bores north of the river affected the process?
 - Are the initial heads in the Tertiary sediments and Weathered zone representative of the observed groundwater system in these units? Has the use of dry bores in the Weathered zone affected the process?
 - Has the use of many more head change targets than absolute heads in the history matching process resulted in poorer matches between simulated initial heads and observed heads?
6. Has the modelling approach which does not include landholder water use from bores, in particular the Joe Joe to the south of the lease, resulted in predicted mining impacts in this area that match the head change targets?

The GMMP Review report, Appendix A now includes predicted drawdowns in Joe Joe formation bores in the Mellaluka Springs area of between 60 and 80 m for the open cut only scenario. This is an increase from previous predicted drawdowns (under the 2013 SEIS model) which were less than 1 m for these same bores. Are these increases realistic? Have they been influenced by the lack of landholder water use being included in the model in this area?
7. Does the modelling of the open cut mining only scenario (including parameters used and methodology of the uncertainty analysis) provide an appropriate level of confidence in the predicted impacts to DSC?
8. What additional geological work with respect to the extent of the Clematis Sandstone and Dundas Beds is required to improve the confidence in the modelling outputs for the optimisation model?

9. Have all the additional works as recommended by CSIRO/GA in 2019 been addressed (whether completed or not) to your satisfaction in particular to support the identification of the source(s) aquifer(s)?
10. Has sufficient isotopic work been undertaken to advance our understanding of the source aquifer? GABSprings Research Report 1.
11. What matters must be addressed to the model methodology prior to undertaking an Optimisation model of mining activities to ensure no greater than 0.2m drawdown at DSC?

GMMP report

1. Does CSIRO/GA support the use of GW thresholds based on the open cut only model scenario?
2. Do you support the Bravus proposed additional monitoring bores and locations? Do you support DES recommendations for additional bores? Any additional bores?
3. What action should be taken if the actual monitored rates of groundwater drawdown are faster than predicted?
4. In order to address ongoing and upward trending water quality trigger exceedances – what do you recommend as an appropriate action?
5. Please provide advice on the suitability and reliability of the use of VWP monitors.

3 Evidentiary basis of review

The reports supplied for review were:

- **Document 1.** EMM (2022), “RP1.6 Hydrogeological conceptualisation review and updated groundwater – Report No. 1 Data review and conceptualisation report”, Prepared for Bravus Resources, June 2022.
- **Document 2.** EMM (2023), “Carmichael Coal Mine Report No. 2: Numerical groundwater flow model report”. Prepared for Bravus Resources, February 2023.

After an initial review of the documents, a series of questions were posed to EMM. Those questions and the corresponding responses provided by EMM are attached (Attachment A) and referred to as:

- **Document 3.** EMM (2023) Carmichael Coal Mine numerical groundwater flow model report – additional information - Memorandum dated 20th February 2023

Other ancillary documents not directly linked to the project that were used during this peer review are:

- **Document 4.** 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 (herein referred to as the AGMG).
- **Document 5.** Commonwealth of Australia (CoA), (2018), *Information guidelines for proponents preparing coal seam gas and large coal mining development proposals*, Commonwealth of Australia, May 2018.
- **Document 6.** 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.

I have not reviewed any other groundwater investigations that have been undertaken since the approval of the CCM, but rather have relied on the information as provided in Document 1.

4 Model Objectives

The model objectives are provided in Section 1.3 of Document 2. In summary, the objectives of the modelling exercise are to provide a revised / updated model that addresses the requirements outlined in the EA Condition E9, and incorporates the updated conceptual model that has been informed by studies and data collection undertaken since the Supplementary EIS (SEIS)¹.

¹ GHD, 2013, *Carmichael Coal Mine and Rail Project SEIS, Appendix K1: Mine Hydrogeology Report*, report prepared for Adani Mining Pty Ltd.

5 Response to Condition E9 of the Environmental Authority.

The following section lists the requirements of condition E9 of the EA, and my comments on how the documents provided have addressed these requirements.

a) *a review of the hydrogeological conceptualisation used in the previous model*

Document 1 provides this review and incorporates the studies undertaken post the SEIS into the current conceptual model. These studies provide more information on the source of water to the nearby springs including the Doogmabulla Springs complex which Bravus has committed to not impacting. The document compares the updated conceptual model with the understanding of the conceptual model at the time the SEIS was prepared. It includes a list of previous criticisms of the SEIS study and how the updated conceptual and numerical modelling addresses these comments (see Table 13.2 of Document 1).

b) *an update of the predicted impacts*

The groundwater model report (Document 2) provides basecase predictions of drawdown in the key hydrostratigraphic units including the Clematis Sandstone and the AB coal seam for three scenarios. The results of the first scenario that simulates only the open cut mining are further explored through uncertainty analysis. The uncertainty analysis explores the influence of different realisations of parameters on model predictions, and concludes that drawdown at the spring locations is less than the threshold of 0.2 m.

c) *a revised water balance model*

Section 10 of the conceptual report (Document 1) describes groundwater and surface water interaction and presents the data that is available and has been collected since the SEIS. There is a water balance provided with a focus on the springs (see Fig 10.34 of Document 1). A water balance is also provided in Section 5.2 of Document 2.

d) *a review of assumptions used in the previous model*

The numerical model assumptions associated with the model build are described in Section 3 of Document 2.

e) *predictions of changes in groundwater levels for a range of scenarios*

The numerical model was used to simulate three scenarios:

1. open cut only;
2. open cut and underground applying the SEIS fracture height; and
3. open cut and underground, with an updated estimate of fracture height applied.

Further to these, the uncertainty analysis explored 105 realisations of parameter distributions creating a range of predicted water levels and allowing for statistical summaries and probability distributions to be created.

f) *any changes made since the previous model review, including data changes*

This is covered in both Document 1, and in Section 3 of Document 2 where the model design is discussed.

g) *a justification for the refined model and the outputs of the refined model*

Changes in the conceptual model and the numerical model are supported by the additional studies and data collected since the SEIS. Document 1 describes the updated understanding of the groundwater regime resulting from the further data collection. Document 2 explains the updates to the conceptual model and associated changes to the model design.

h) *an evaluation of the accuracy of the predicted changes in groundwater levels, groundwater flow rates to surface water and recommended actions to improve the accuracy of the model predictions*

Document 2, Section 4 describes the history matching conducted for the updated model, which is a process intended to improve the accuracy of model predictions. Section 7 of Document 2 provides a series of recommendations for future data collection and updates to the model intended to improve the history matching ability of the model and reduce the range of uncertainty in future predictions. Ultimately the accuracy of predictions can only be assessed in hindsight once further data becomes available.

i) *an independent peer review and certification that the environmental authority holder has undertaken the review in accordance with all commitments in the GMMP*

This document is intended to address this condition.

6 General review comments

6.1 Model design

The following comments are provided on the updated model design:

- The model has been completely rebuilt using new software, and an improved understanding of how the groundwater systems within the main hydrostratigraphic formations may interact, including more information on the source for the Doongmabulla springs from studies undertaken by Bravus per the licence requirements.
- The model extent has been kept consistent with the previous SEIS modelling. This has been driven by the objective to make comparisons to the previous work.
- Conceptually the model domain is a flowthrough system from west, north and south, to the east. This process has been simulated with constant heads in the model. This approach can drive water levels within the model domain and can interrupt the ability to conduct water level history matching. Upon initial inspection the model boundaries appeared to be sufficiently distant to prevent this being a significant issue, however review of the maximum drawdown in the coal seams indicates drawdown does reach the model boundary in the west.
- The springs have been represented by assigning the drain return flow boundary condition to the Clematis Sandstone at the respective spring locations. This boundary condition allows for the distribution of water removed from the Clematis source formation to be returned as recharge to layer 1 in the model, thus replicating the spring flowing to the surface. This approach is considered appropriate.
- Faults have not been specifically modelled as there is little evidence of significant faults occurring in the mining area. This approach is considered acceptable as the model represents some spatial variability / heterogeneity in hydraulic properties that has the potential to capture the influence of any unknown faults if there is a differing water level response on either side.

6.2 Model history matching

The following comments are provided on the history matching process and outcomes:

- It is commendable to see the observation dataset used for history matching includes both absolute water level, as well as relative change / water level behaviour. This is good practice.
- It is not clear if there was an opportunity, and sufficient data, to utilise baseflow recorded at new surface water gauging sites on the local creeks in the history matching process, but this is recommended in further model iterations as the dataset available expands.
- The level of 'fit' achieved during the history matching process is considered acceptable, although there might be some systematic boundary condition influence in the lower discharge areas of the model, as evident in the pre-mining scatter diagram. Here the flattening of scatter and inability of predictions to fall below 215 mAHD indicates a structural influence, likely why the SRMS value for these absolute observations were higher at around 10%. More detail was requested from EMM on this aspect through Question 7 of Document 3 and they confirmed structural controls were likely influencing water level predictions in this area of the model.
- Reviewing the base case parameter distributions in Appendix B of Document 2, it is apparent that a number of the datasets, particularly for specific yield for deeper units have a basecase and the majority of realisations assigned to the upper bounds. In the case of specific yield this has numerous formations with a value of 0.1 (or 10%). This is potentially a higher value than typical and is resulting in predictions of relatively large groundwater inflows to the mining areas.
- The calibrated specific storage value distributions are biased towards low values for the deeper formations, particularly the coal seams, with values reaching their theoretically lowest plausible value, and potentially not representative of the coal seams even at depth. The outcome of this assumption is predicted drawdown within the coal seams will propagate further and at a quicker rate than would occur with less extreme values.
- Through the history matching process there will always be bores that don't match well, or have a poor match in favour of better matches at a numbering of neighbouring bores. Some of the hydrographs presented in Appendix C demonstrate this. However, where there is a mis-match in the starting water level, the model is generally still able to replicate the observed water level trend.

6.3 Model predictions

The following comments are provided on the model predictions:

- Three scenarios were developed which provide insight into the impact of underground mining over just open cut mining, and also the influence of the different fracture height estimates.
- The 'high-K' lake is approach to represent the residual void lake. This approach uses very high values of hydraulic conductivity and storage to represent the open void remaining post mining. The hydraulic conductivity value assigned is nominally high enough to readily connect water between model cells (as would be expected within a lake), and the specific yield value of 100% means that the entire volume of the cell is available to receive water and the unconfined water level changes linearly with added or removed water. Once the water level in the void cell gets high enough, the cell becomes confined (the water level moves above the top of the model cell and starts saturating the cell above). At this point the storage properties of the cell that is confined are described by the specific storage. EMM have assigned a specific storage value of $1.3 \times 10^{-5} \text{ m}^{-1}$ (note there is an error in Document 2 which records the units as m/d, rather than m^{-1}). The adopted value is at the theoretical upper limit of plausible specific storage values in confined media. This means that despite the cell being 'full', the high specific storage means that the cell can continue to receive water. When the cell is full, the value assigned to specific storage should approximate the compressibility of water, with a value of $5.0 \times 10^{-6} \text{ m}^{-1}$. The implications for the model are that the final void water level will fill slower and ultimately be at a lower predicted level for the given inputs. I raised this with EMM and they acknowledged the error (see Question 4 in Document 3). I recognise the equilibrium water level in a void is a balance between the inputs (rainfall recharge and runoff, groundwater inflow) and outputs (evaporation), and in most cases groundwater inflow is significantly smaller than the other components. This means that the influence of this parameter is likely to be small. This issue could be overcome by adding a steady state stress period to the end of the transient post mining recovery to provide the equilibrium levels. Based on the hydrographs in Document 2 Appendix D it is not clear if a pseudo steady state in water levels has been reached at year 4000.
- Document 2 Figure 3.33 indicates the pit void depth which is assumed to be the final landform. I can appreciate that the detailed planning around what the final landform will look like may not be available at this point in time, but I would have expected the backfilling in the pit to bulk up and not be starting at 3 m or more below surface topography for areas along the eastern side of the pits.
- There are no equilibrium / long term drawdowns provided in the report. It would be helpful to visualise where the extent of the pit lake is within the pit extent.
- Water budgets indicate the dominant component is throughflow – water coming in from the west, north and south, and exiting the model domain as either evaporative losses or as throughflow in the east. This representation is supported by the conceptual model, and reflects the concept adopted in the original SEIS model. The assigned constant heads at the western boundary are influencing drawdown extents in the coal seams (and possibly other layers). This can be seen in Document 2 Figures 5.9 to 5.11, with the drawdown becoming zero right around the boundary. Given the dominant volume of throughflow in the model budget I posed Question 13 in Document 3. EMM confirmed that the budget does change in the predictive phase with an increase to the net inflow of 14 ML/day. The drawdown reaching this boundary is a function of the low coal seam specific storage. This will be a feature that needs review in future model updates, particularly as the specific storage values are refined through history matching to water levels influenced by nearby mining.

6.4 Uncertainty analysis

The following comments are provided on the uncertainty analysis:

- The uncertainty analysis has been undertaken on the scenario that simulates the 'open cut only' mining. The report does not treat the uncertainty analysis as a separate exercise, rather it is woven through the various prediction reporting. There is only one drawdown contour plot presented and this is for the Clematis Sandstone. This is an appropriate hydrostratigraphic unit to focus on as evidence to date suggests this is the likely water source for most of the springs in the area.
- The calibration results show not only the basecase model results, but also the results from the other 104 realisations that form the uncertainty analysis. This approach is helpful as it provides insights into the variability of predictions from each history matched model.
- Drawdown hydrographs are provided for observation bores and at spring locations in Document 2 Appendix D (for the open cut only scenario) and show all the realisations as well as the probabilities of the drawdown being less than the indicated hydrograph. These graphs all show the critical spring drawdown, however it is only necessary to show on hydrographs that represent spring predictions.

7 Confidence level classification

The Australian groundwater modelling guidelines provide a method of assessing a model's confidence level and infers typical uses for a model based on specific characteristics. Document 2 did not include a 'self-assessment' according to the modelling guidelines, and as such I have undertaken this as part of the peer review process.

Under the guidelines, this model would be classified as a Confidence Level 2 groundwater model, with the following key indicators (based on Table 2-1 of Barnett et al., 2012):

- rainfall and evaporation data are available for the site (Level 3);
- groundwater head observations and bore logs are available and with a good coverage around the Carmichael site, but without spatial coverage throughout the model domain (Level 2);
- some site and field properties are available, but missing some estimates of storage (Level 2);
- scaled RMS error and other calibration statistics, e.g. mean residual, are acceptable (Level 3); and
- Transient calibration and predictions are conducted (level 2).

The indicated use for the model based on this classification is for the assessments of impacts.

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Table 7.1 Confidence Level Classification (After Table 2-1, Barnett et al, 2012)

Class	Data		Calibration		Prediction		Quantitative Indicators	
1 (Simple) Count=0	×	Not much	×	Not possible	×	Timeframe >> Calibration	×	Timeframe > 10x
	×	Sparse coverage	×	Large error statistic	×	Long stress periods	×	Stresses < 5x
	×	No metered usage	×	Inadequate data spread	×	Poor/no validation	×	Mass balance > 1% (or one-off 5%)
	×	Low resolution	×	Targets incompatible with model purpose.	×	Transient prediction but steady-state calibration	×	Properties < > field values
	×	Poor aquifer geometry					×	No review by Hydro/Modeller
2 (Impact Assessment) Count=12	×	Some	✓	Partial performance	✓	Timeframe > Calibration	×	Time frame = 3-10x
	✓	Ok coverage	✓	Some long term trends wrong.	×	Long stress periods	×	Stresses = 2-5x
	~	Some usage data/ low volumes	✓	Short term record.	×	Ok validation	✓	Mass balance <1%
	×	Baseflow estimates. Some K & S measurements	~	Weak seasonal match.	✓	Transient calibration and prediction	✓	Some properties < > field values. Review by Hydrogeologist
	✓	Some high resolution topographic DEM &/or some aquifer geometry	✓	No use of targets compatible with model purpose (heads & fluxes)	✓	New stresses not in calibration	×	Some coarse discretisation in key areas of grid or at key times
3 (Complex Simulator) Count=9	~	Lots, with good coverage.	✓	Good performance stats	×	Timeframe ~ calibration	×	Timeframe < 3x
	~	Good metered usage info.	×	Most long term trends matched	×	Similar stress periods	×	Stresses < 2x
	✓	Local climate data	~	Most seasonal matches ok.	×	Good validation	✓	Mass balance < 0.5%
	~	Kh, Kv & Sy measurements from range of tests	✓	Present day data targets	×	Calibration & prediction consistent (transient or steady state).	~	Properties ~field measurements
	×	High resolution DEM all areas.	×	Head & Flux targets used to constrain calibration	×	Similar stresses to those in calibration.	✓	No coarse discretisation in key areas (grid or time)
	~	Good aquifer geometry.					✓	Review by experienced Modeller

Notes:
Criteria met = ✓
Criteria partially met = ~
Criteria not met = ×

8 Compliance checklist

The Australian groundwater modelling guidelines provide a generic compliance checklist to assess a model at a high level. Because this assessment has relied on the reporting and not examined model files, nor the background reporting underpinning the conceptual model update, this is the most appropriate level to comment at. The 10 questions that form this checklist cover essential elements of a groundwater model.

The checklist is sourced from Table 9-1 of the Australian groundwater modelling guidelines (Document 4).

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Table 8.1 Compliance Checklist

Question	Yes / No	Comment
1. Are the model objectives and model confidence level classification clearly stated?	Yes	The model objectives are outlined in Section 1.3 of the Document 2. The report does not provide a self assessment of the confidence level classification, but one has been carried out as part of this review.
2. Are the objectives satisfied?	Yes	The updates to the conceptual model presented in Document 1 have been amalgamated into the updated model (see Section 4 of this review).
3. Is the conceptual model consistent with objectives and confidence level classification?	Yes	While there is no self-assessed confidence limit provided in the reporting, one has been undertaken for this review and assessed the model as having a confidence level classification of Level 2. This is supported by the additional data that underpins the conceptual model assumptions and the conceptual model
4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	Yes	The conceptual model has been presented in Document 1. It was peer reviewed by Dr Noel Merrick who is appropriately qualified to review the document.
5. Does the model design conform to best practice?	Yes	<p>The model uses the most up to date industry standard software (MODFLOW-USG) and applies features (such as adopting Voronoi cells in the mesh) that are best practice.</p> <p>The design has been a little constrained by needing to be comparable to the previous model in some places, such as model extent.</p> <p>The model utilises a transient pre-mining 'warm up' stage to help with solving the steady state model representing pre-mining conditions.</p>
6. Is the model calibration satisfactory?	Yes	<p>The calibration statistics satisfy targets, however the scatter diagram indicates some systematic mis-match – assumed to be due to boundary condition influence, and confirmed by EMM in response to Question 7 in Document 3.</p> <p>The calibration process has been thorough and has utilised emerging techniques with PESTPP-IES and ensemble smoothing to reduce the computational effort.</p> <p>The methodology and approach were sound and following the principles of the GMDSI, whereby after some initial range finding calibration with single values, the model was assigned a significant amount of pilot points totalling 30960 (7,740 per hydraulic parameter) to describe heterogeneity in the system and later explore parameter uncertainty.</p>

Question	Yes / No	Comment
7. Are the calibrated parameter values and estimated fluxes plausible?	Yes	<p>Many parameters are matching to the conceptual model and field data that underpins it. However, some resulting hydraulic properties from the calibration, particularly the storage properties have calibrated to the predefined upper and lower bounds. This could be an indication of insensitivity in the parameter and the calibration process searching to make those parameters more sensitive and reaching the bounds. This aspect was explored in Question 9 of Document 3 (attached).</p> <p>It is noted that the calibrated steady state and transient water budgets are dominated by throughflow. This was a feature of the SEIS model and is part of the conceptual model.</p>
8. Do the model predictions conform to best practice?	Yes	<p>The predictive phase and the simulation of the mine dewatering through drains and applying property changes within the fracture zone, are aligned to best practice. The reporting is not clear on the exact details of how the mining progresses, but further information was provided by EMM in response to Question 1 in Document 3. Backfilling of spoil seems to be made at the end of mining.</p> <p>There is a tabulated schedule that indicates that mining remains active in the mining domains once it starts all the way through to the end of mining in 2075. The TVM package is used to make changes to hydraulic properties prior to the post mining phase of the predictions and this can be considered current best practice.</p> <p>Fracture height calculations using best practice have identified a significant change in a previous assumption for this value, thus the formulation of a number of prediction scenarios to explore the difference that this change creates.</p> <p>The presentation of drawdown within the model results comes from the maximum drawdown experienced at that location both during and after mining, which can be considered best practice.</p> <p>There has not been any climate change scenarios run. This included in the next model update.</p>
9. Is the uncertainty associated with the predictions reported?	Yes	<p>Hydrographs at bores and the critical 0.2 m drawdown in the Clematis Sandstone are presented with probabilistic measures. There is no uncertainty analysis provided for the mine inflow predictions, though EMM's response to Question 11 in Document 3 indicates that spot checks were carried out with some of the realisations which suggest variability of $\pm 20\%$ from the basecase prediction.</p>
10. Is the model fit for purpose?	Yes	See Section 9 below.

1.3 Question 3

Q: In regard to the ramp function for fracture zone changes (section 3.5.5 iii), my understanding is that this gets applied to each model cell in the fracture zone (within 230m above the caved zone), where the cell elevation (from centroid?) is applied to the log-linear relationship between to get a new K at that location. Initially, and based on the figure, I thought this could have been relying on whatever host K existed at the 230m above cave zone, and then the interpreted change using that host K for all the layers in that cell column. I think I understand it better now. With that in mind, is this applied to both Kh and Kv, using their respective host K values? As the 230 m was an average from the Merrick 2021 calcs, what was the range? Has Hmax been allowed to vary from location to location (possibly cell by cell)? I am asking because the fracture height calculation uses overburden thickness and I wonder how much this varies across the planned underground footprint.

A: Your understanding of elevation from centroid is correct, as is the modification to the in-situ hydraulic conductivity. This was applied to both Kh and Kv, with the assumption that Kh = Kv in the cave zone. Hmax was held constant for the full mine footprint, acknowledging the variance for the actual mine plan. This is a simplifying assumption that would have an impact on modelled property changes, but it was considered during model design that the uncertainty in estimated fracture height, cave zone properties, and ramp function did not justify the full detail being represented in the groundwater model.

1.4 Question 4

Q: In post mining recovery (Section 3.5.5 iv) the specific storage term for the void is reported to be " 1.3×10^{-5} m/d". Looking beyond the incorrect units, this value is very high. The usual approach in a 'high-k' lake is to apply a specific storage equivalent to the compressibility of water. Once the water level in a cell representing the void reaches the top of the cell, that cell becomes confined in the model and the water level moves above the top of the model cell and starts saturating the cell above. When this happens, any additional water received by the fully saturated (confined) void cells should be effectively passed to the partially saturated cell above as there should be no additional storage available in the confined cells. Applying a value at the upper bound of specific storage (like that reported) means that this cell will continue to store water that flows into it from surrounding strata, which will ultimately lead to an under prediction of the water level in the void with time, and result in a lower equilibrium water level. It is impossible to say if this will change the conclusion that the final void/s will act as a sink, I suspect not, but I can't be sure.

A: Acknowledged but given that the post-mining recovery period is run to pseudo steady-state, the values for storage do not influence final modelled groundwater elevations (it more so affects the rate of recovery). The mine is conceptualised to remain a sink because the voids are only backfilled to the coal seam elevations, yet the pre-mining watertable is much higher.

1.5 Question 5

Q: The use of the CLN package in the void is clever, but does it remove the influence of the pit geometry (i.e. lower evaporation due to limited wind, shade, etc), or is that accounted for in other ways?

A: That is accounted for by reducing the maximum 'evaporation' rate to 70% of pan evaporation. Again, this is a simplifying assumption but one we typically use to account for geometry impacts for pit void recovery problems. The CLN package was also chosen to promote numerical stability.

1.6 Question 6

Q: There is no presentation of post mining equilibrium groundwater conditions. Is this not required for the project? Water levels at some key bores are shown post mining, but that does not give the overall picture post mining.

A: No request has been made for post-mining groundwater conditions beyond simulated drawdown. However, we agree that a final modelled groundwater contour map would be useful from a readers perspective.

1.7 Question 7

Q: Looking at the scatter diagram (Fig 4.12) for pre-mining conditions, there seems to be a systematic flattening of predicted water levels. Is there something in the model (i.e. boundary condition elevation around 215 mAHD) that might have led to this? I noticed reasonable amount of alluvium and weathered hydrographs were over predicting around that 10 to 20m range. On the other hand, some were well under. Could the over predictions be the influence of stream recharge in the steady state? The hydrographs did seem tight across the range of realisations pointing to a boundary condition influence.

A: There are definite structural controls preventing improved history-matching performance and leading to tighter hydrographs in the uncertainty suite. This was observed through the history-matching process. An improvement we are happy to make is to add a spatial residual map with some supporting commentary. This would clearly show areas where the model over simulates modelled heads and, perhaps, underpredicts discharge processes.

1.8 Question 8

Q: In the hydraulic properties comparison (Table 4.5), does hydraulic conductivity refer to both K_h and K_v ?

A: Yes. Comparisons are slightly 'fuzzy' due to the range of values in the updated model. We can add further clarity in Section 4.4.1 text.

1.9 Question 9

Q: Looking at the basecase parameter distributions in Appendix B, it is apparent that a lot of parameters have clustered around their upper and lower bounds. From memory this was a 'feature' of the ensemble smoothing process. Was there consideration given to that during the history matching phase?

A: Yes, and there was an apparent trade-off between history-matching performance and parameter clustering around the assigned bounds. The reported values were developed to provide as close a match as possible to measurements, acknowledging the influence this would have on clustering. Note that the presented histograms are not for an individual parameter at a single pilot point, but for all pilot point values across an HSU/model layer.

1.10 Question 10

Q: A number of the specific yield values for various deeper units (including the coal seams) have gone to 0.1 (10%), while the corresponding specific storage values are at the theoretical lowest values. Is that result expected and in line with the conceptual model? These values will have an influence on the inflow volume to the mine.

A: The values are highly significant for modelled mine inflows; an increase in S_y compared to previous modelling resulted in a proportional increase in modelled inflow. As discussed in-text, these parameters should be prioritised for future modelling to improve predictive accuracy. In the next 5-year modelling phase, there will be a significant amount of drawdown data to support history-matching within the Permian and thus a tighter range on S_y should be achievable. It is acknowledged that, as it is, the model is likely overpredicting mine inflows. In terms of modelled vs measured aquifer properties, EMM is happy to add box-and-whisker plots within the history-matching chapter to assist with this comparison.

the Doongmabulla Spring Complex of more than the 0.2m that is permissible in the relevant mine approvals and the Groundwater Management and Monitoring Program”.

4. On 23 February 2023, you provided the department with a letter regarding EA EPML01470513 – revised groundwater modelling which further states *“The revised modelling indicated that on the current underground mine plan, underground mining operations at the Carmichael Mine would result in groundwater drawdown at the Doongmabulla Springs Complex which exceed the 0.2m interim drawdown threshold”.*
5. Condition A3 of your EA authorises underground mining. However, your EA also requires compliance with conditions E4, E9 and I11.
6. Conditions E4 and I11 requires you to develop and implement a Groundwater Management and Monitoring Program (GMMP) and a Groundwater Dependent Ecosystems Management Plan (GDEMP) respectively.
7. Condition E9 requires you undertake review of the groundwater model to be completed by 10 October 2022 and at least every 5 years thereafter, or at other intervals specified by the administering authority in writing.
8. The groundwater model and its review inform the GMMP and GDEMP as part of an adaptive management framework.
9. Section 5.3.5.3 of your GMMP states that the approved level of impact *“limits the drawdown to 0.2m at the Doongmabulla Springs Complex”.*
10. Section 7 of your GMMP and Section 5.9 of your GDEMP state that should any groundwater model re-run determine that unauthorised impacts to the Doongmabulla Springs Complex may occur, you will:
“Freeze [underground] mine development at current levels until the completion of investigations and assessments which demonstrates and concludes that further development will not exceed approved impacts”.
11. As set out in paragraph 3 above, the Groundwater Model Report has determined that unauthorised impacts to the Doongmabulla Springs Complex may occur should underground mining commence.
12. Therefore, the department considers it necessary to issue you with this EPO in order to pause the commencement of underground mining until such time as you can demonstrate to the satisfaction of the department that the activity can be conducted in a way that does not exceed the approved impacts.
13. Specifically, the department is imposing the requirement for you to implement the commitment in your GDEMP and GMMP to freeze mine development by not commencing underground mining.
14. In this EPO, the department is specifying the “investigations and assessments” required to demonstrate and conclude that underground mining will not exceed approved impacts.
15. Further, condition E9 provides (among other things) that the department may require further Groundwater Model Review Report reviews to be completed if the observed groundwater levels and groundwater flow rates to surface water are not consistent with those predicted by the groundwater model.
16. According to your Groundwater Model Report, groundwater levels differ from those predicted in the 2013 SEIS groundwater model and exceed the approved impacts.
17. Therefore, this EPO requires you to conduct a Second Groundwater Model Review Report and pause the commencement of underground mining until you can demonstrate to the satisfaction of the department that the activity can be conducted in a way that does not exceed the approved impacts.

B. Requirements

1. You must undertake a second groundwater model review in accordance with the requirements of condition E9 and produce a second review report (the **Second Groundwater Model Review Report**).
2. The Second Groundwater Model Review Report must be submitted to the administering authority by **1 October 2023**.
3. The Second Groundwater Model Review Report must:
 - a) detail the findings and recommendations from the first groundwater model review;
 - b) address the findings and recommendations of the independent peer review of the first Groundwater Model Review Report;
 - c) demonstrate that all feedback from the administering authority, CSIRO and Geoscience Australia with respect to the first Groundwater Model Review Report have been addressed and incorporated in the second groundwater model review; and
 - d) include an updated mine plan to replace Table A1 and Figures A1 and A2 in the current EA.
4. You must not commence underground mining until the following actions have been completed:
 - a) A Second Groundwater Model Review Report is provided to the department that demonstrates that mining activities will only result in a predicted drawdown of 0.2m or less (with a 95% confidence interval) at the Doongmabulla Springs Complex; and
 - b) The Second Groundwater Model Review Report is approved by the administering authority;
 - c) The updated GMMP required under EA condition E8 is approved; and
 - d) The EA is amended to include an updated mine plan which reflects any changes to mining activities required to be made as a result of the approved Second Groundwater Model Review Report.
5. You must not carry out any mining or associated activities that would result in an exceedance of the interim drawdown threshold of 0.2m at the Doongmabulla Springs Complex.

C. Obligations

If you propose to dispose of the place or business to which the EPO relates, you **must** advise the buyer of the existence of this EPO.

If you cease to carry out the activity to which this EPO relates, you **must** give written notice of ceasing to carry out the activity to the department within 10 days of ceasing the activity.

Take notice:

- the requirements of this order take effect immediately upon service of the order;
- failure to comply with this order is an offence under the EP Act;
- this order remains in force until further notice from the administering authority.

D. Penalty

It is important that you know the impact to you personally as an individual or as a corporation for not meeting your obligations.

Failure to comply with an EPO is an offence.

- The maximum penalty for a corporation wilfully contravening an EPO is \$ 4,492,187.50.
- The maximum penalty for a corporation contravening an EPO is \$ 3,234,375.00.

Failure to provide written notice to the buyer of the existence of the order is an offence.

- The maximum penalty is 50 penalty units, totalling \$ 35,935.00 for a corporation

Failure to provide written notice to the department within 10 business days of ceasing the activity to which an environmental protection order relates is an offence.

- The maximum penalty is 50 penalty units, totalling \$ 35,935.00 for a corporation.

Section 3 of the *Penalties and Sentences Regulation 2015* prescribes the monetary value of a penalty unit.

E. Reviews and appeals

The provisions regarding reviews of decisions and appeals are found in sections 519 to 539 of the EP Act.

A person who is dissatisfied with an original decision made by the Department of Environment and Science (the department) may apply to have that decision internally reviewed.

Information about initiating an appeal in relation to this notice is contained within the [Internal Reviews and Appeals Information Sheet](#) (available at www.qld.gov.au using the publication number ESR /2015/1742 as a search term)

A request for review or appeal is to be made using the approved form '[Application for review of original decision](#)' (available at www.qld.gov.au using the publication number ESR/2015/1573 as a search term.

Applications for reviews are to be sent to Permit and Licence Management, Department of Environment and Science: via email at palm@des.qld.gov.au , or by mail to the following address: GPO. Box 2454, Brisbane, QLD, 4001.

Where an application has been made for a decision to be reviewed, the applicant may also apply to the relevant court for a stay of the decision to secure the effectiveness of the review.

Once the original decision has been reviewed, a person who is dissatisfied with the review decision may be able to appeal against that decision to the relevant court within 22 business days after receiving notice of the review decision.

A person whose interests are or would be adversely affected by a decision of the department may be able to request a statement of reasons for a decision or a statutory order review under the *Judicial Review Act 1991*.

You may have other legal rights or obligations and should seek your own legal advice.

Pursuant to section 540 of the Act, the department is required to maintain a register of certain documents and information authorised under the Act. A copy of this document will be kept on the public register. The register is available for inspection by members of the public who are able take extracts, or copies of the documents from the register. Documents that are required to be kept on the register are published in their entirety, unless alteration is required by the Act. There is no general discretion allowing the department to withhold documents or information required to be kept on the public register. For more information on the department's public register, search 'public register' at www.qld.gov.au. For queries about privacy matters please email privacy@des.qld.gov.au or telephone 13 74 68.

Should you have any queries in relation to the notice, please contact Tony Baker on (07) 48373499 .

of the EA were developed requiring regular re-runs of the original modelling over time using real data collected since mining commenced.

The aim of this approach is that as research and monitoring information becomes available, the model is refined and uncertainty is reduced.

This results in a more accurate model, ensuring the early detection and prevention of any potential future impacts to the Doongmabulla Springs Complex due to mining operations.

Adaptive management also provides the opportunity for an operator to modify its mining activities where necessary to mitigate those impacts.

DES has received the first groundwater model re-run report from Bravus about its predicted modelled impacts at its Carmichael coal mine.

The next model re-run Bravus is required to undertake in accordance with its EA is due in 2027, six years prior to commencement of underground operations. However, based on the results of the first re-run, Bravus has committed to undertaking a re-run sooner.

DES has now formally required Bravus to complete a second re-run and provide an updated report later this year. The department has directed that any feedback from the CSIRO and Geoscience Australia must be incorporated into the second model re-run.

The department has also included a requirement that underground mining not commence until the completion of investigations, assessments and modelling that concludes impacts will not exceed the approved drawdown and the re-run report is approved by the department.

ENDS

Media contact: DES Media Unit on (07) 3339 5831 or media@des.qld.gov.au



Queensland
Government

CSIRO/GA Questions

Model Report

1. Does the uncertainty analysis presented in the GW Review report meet the IESC guidelines and will it provide an acceptable/realistic range of potential impacts?
2. Is the methodology used to model the impacts of long wall mining under the SEIS B scenario adequate and appropriate, particularly with respect to prediction of impacts to the Doongmabulla Springs Complex?
3. Has the use of pilot points resulted in a more accurate representation of parameters instead of using one parameter value per layer?
4. Is the model cell size of 500m in the mining areas appropriate especially with respect to identifying longterm impacts from residual voids post mining?
5. Do the initial heads determined in the history matching process adequately represent the observed groundwater heads and groundwater system. In particular:
 - Does the model represent the pre mining groundwater lows observed north of the Carmichael River in the Bandanna Formation, Colinlea Sandstone and Joe Joe formation? Does the model incorporate findings from the conceptualisation?
 - Do the initial heads and simulated groundwater levels in the Carmichael River alluvium adequately represent that aquifer and if not, how might this affect the understanding of surface water-groundwater interaction? Has the use of dry bores north of the river affected the process?
 - Are the initial heads in the Tertiary sediments and Weathered zone representative of the observed groundwater system in these units? Has the use of dry bores in the Weathered zone affect the process?
 - Has the use of many more head change targets than absolute heads in the history matching process resulted in poorer matches between simulated initial heads and observed heads?
6. Has the modelling approach which does not include landholder water use from bores, in particular the Joe Joe to the south of the lease, result in predicted mining impacts in this area that match the head change targets?
7. Does the modelling of the open cut mining only scenario (including parameters used and methodology of the uncertainty analysis) provide an appropriate level of confidence in the predicted impacts to DSC?
8. What additional geological work with respect to the extent of the Clematis Sandstone and Dundas Beds is required to improve the confidence in the modelling outputs for the optimisation model?
9. Have all the additional works as recommended by CSIRO/GA in 2019 been addressed (whether completed or not) to your satisfaction in particular to support the identification of the source(s) aquifer(s)?
10. Has sufficient isotopic work been undertaken to advance our understanding of the source aquifer? GABSprings Research Report 1.

11. What matters must be addressed to the model methodology prior to undertaking an Optimisation model of mining activities to ensure no greater than 0.2m drawdown at DSC?

GMMP report

1. Does CSIRO/GA support the use of GW thresholds based on the open cut only model scenario?
2. Do you support the Bravus proposed additional monitoring bores and locations? Do you support DES recommendations for additional bores? Any additional bores?
3. What action should be taken if the actual monitored rates of groundwater drawdown are faster than predicted?
4. In order to address ongoing and upward trending water quality trigger exceedances – what do you recommend as an appropriate action?
5. Please provide advice on the suitability and reliability of the use of VWP monitors.

Preliminary review of the Carmichael Coal Mine groundwater model report

Initial Heads

Bandanna Formation, Colinlea Sandstone and Joe Joe Formation

There is an area on the northern side of the Carmichael River encompassing the area of current mining, where in the pre mining period the lowest groundwater levels in the Bandanna Formation and Colinlea Sandstone have been noted as have some in the Joe Joe Formation.

In this current report Table 2.1 – Summary of the Conceptual Hydrogeological model, states:

- *A synform had been proposed during the SEIS phase, with a northeast to southwest fold axis that passes broadly through the centre of the site. The synform affects the Betts Creek Beds and Rewan Formation and the fold axis tends to align with a regional potentiometric 'low'.*
- *Two alternative conceptualisations have been recently proposed by EMM (EMM 2022a) as an alternative to the synform: local faulting or a permeable Joe Joe Group acting as an underdrain. The local fault (or higher permeable zone) is conceptualised to cut across the Bandanna, Colinlea and Joe Joe Group mainly within the lease area.*

The table also states, under the heading of local groundwater flow:

Colinlea Sandstone: Groundwater flow converges towards bore C006P3R and is likely influenced by the local faulting/high permeable zone previously proposed.

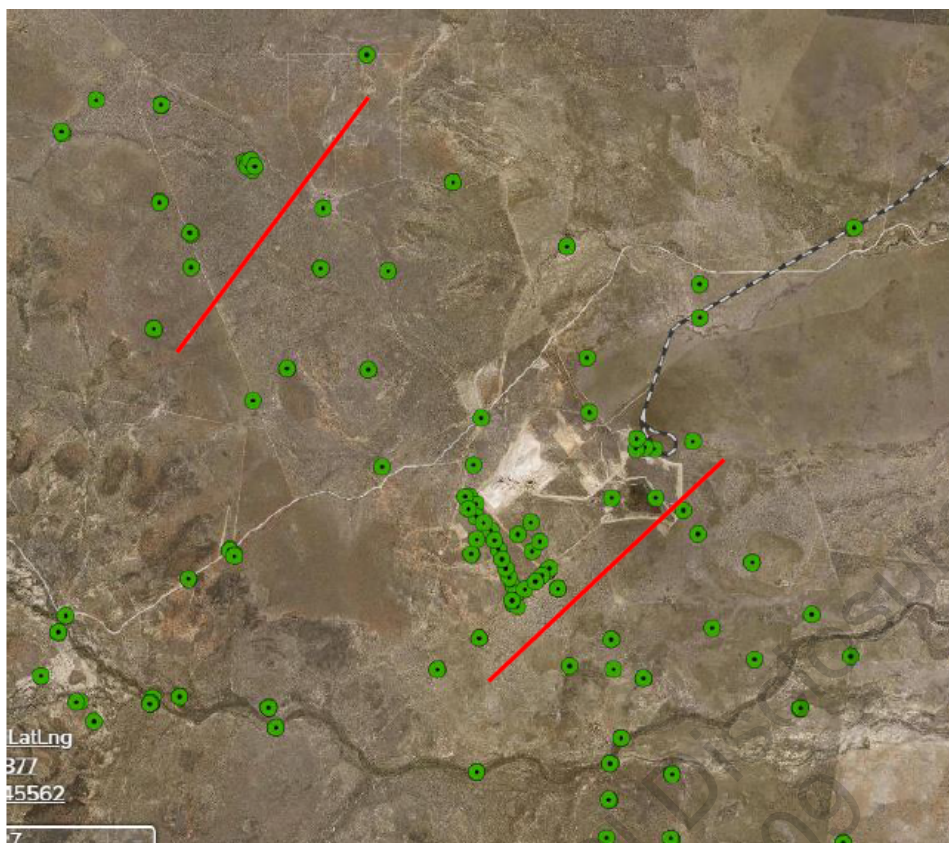
The synform theory is rejected as it does not account for the discharge of groundwater that would be required to cause these groundwater lows.

Whilst EMM have developed alternative conceptualisations they have not incorporated any of these potential discharge processes into the numerical groundwater model.

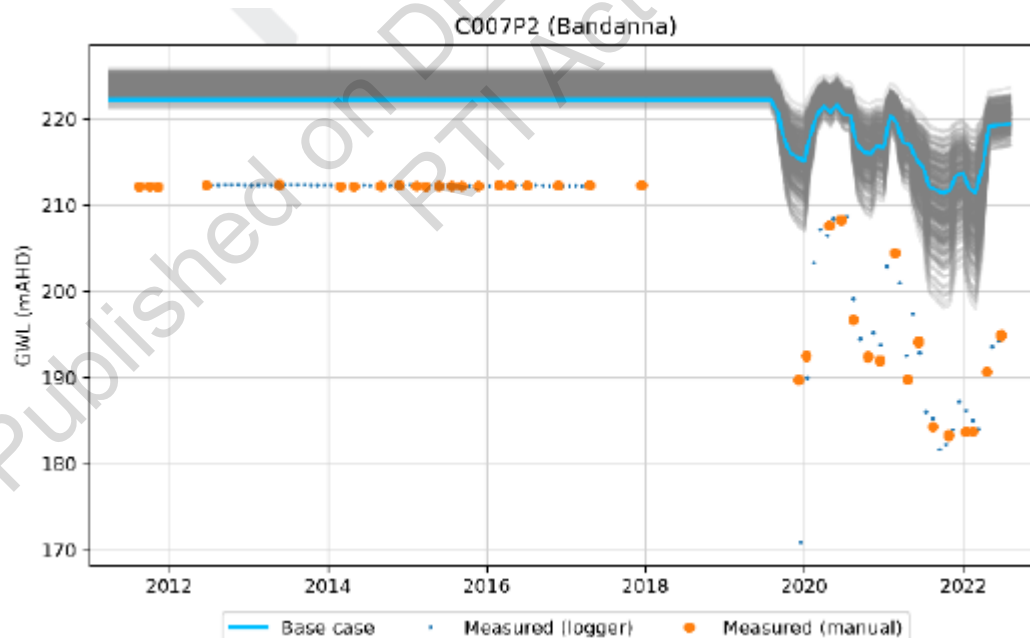
It appears that subsequently the model is unable to replicate these groundwater lows in this area in the pre mining period (pre 2019).

The model simulated initial heads for the calibration hydrographs as provided in Appendix C are therefore generally about 8 to 12 m higher than observed water levels in the Bandanna Formation and Colinlea Sandstone in this area. There are few Joe Joe bores in this area but in two bores located north-east of the current mining the initial heads are 7 m higher than observed water levels.

This is a poor representation of pre mining conditions and not a strong basis for model calibration and prediction in an area where dewatering conditions can provide excellent data for model calibration.

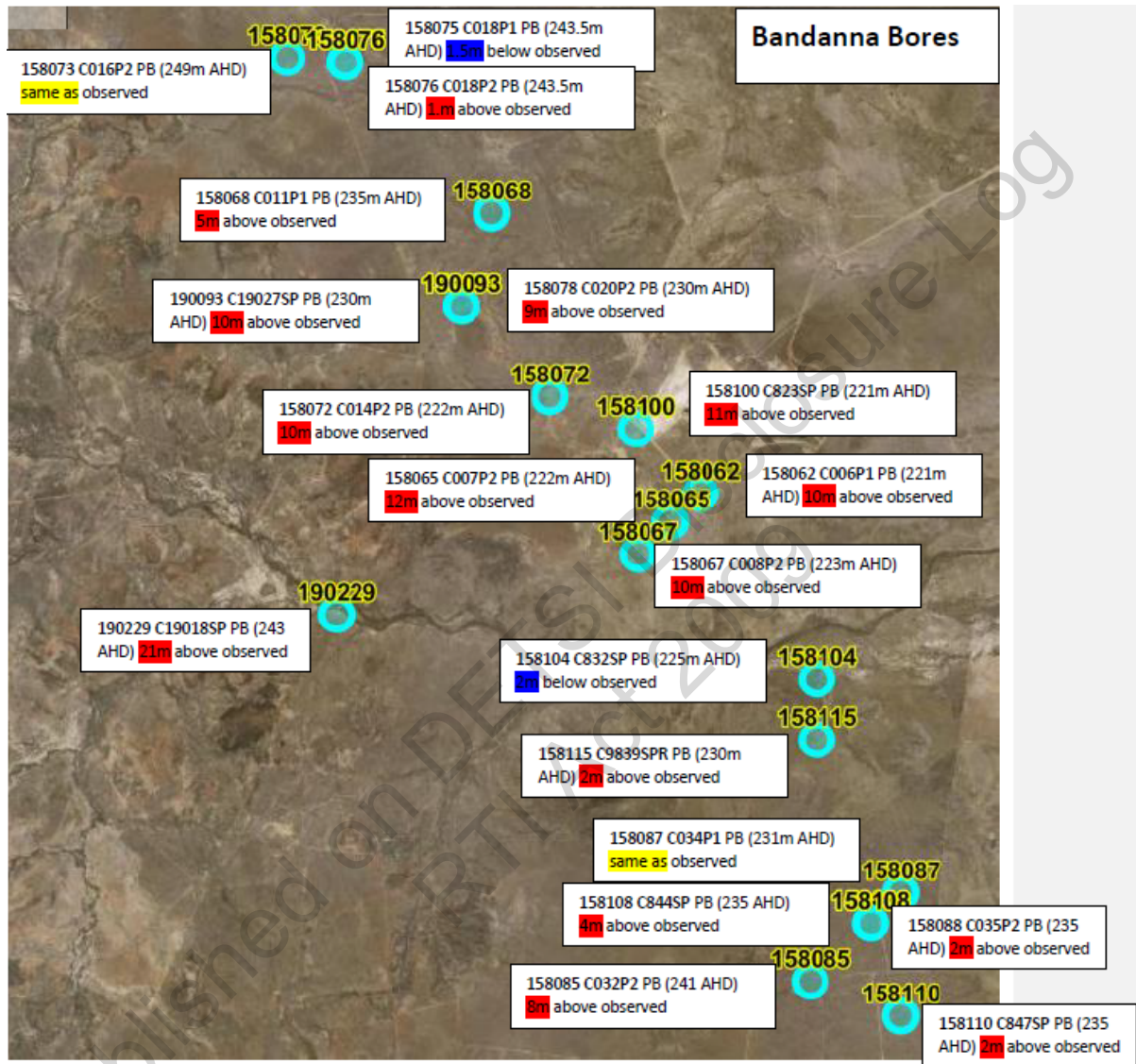


Red lines denote approximate area where model is predicting much higher initial heads than observed water levels in Bandanna, Colinlea and a couple of Joe Joe bores.



C007P2 - Example of an Appendix C calibration hydrograph where modelled initial heads are approx. 12 m higher than observed.

In each geologic unit the calibration hydrographs identified as representing that unit in Appendix C have been examined and an assessment of the variation between modelled base case initial head and observed water level made and then plotted on a map to understand spatial variation of these differences. An example is provided below for the Bandanna Formation. Similar figures are available in Appendix A for all geologic units except the Moolayember.



PB – Predicted Base case initial head

Initial Heads Alluvium

Appendix C contains 5 alluvial bores located in the Carmichael River alluvium. The base case initial heads for these five bores are between 6 and 12 m higher than observed water levels in these bores. This is a poor representation of the alluvial aquifer.

Modelled steady state contours are provided in the report for the Clematis Sandstone, AB Coal Seam and D Coal Seam only. It is not clear how the initial heads for the alluvium was determined.

Given this poor match between simulated and observed heads it is not clear how recharge and discharge processes in the alluvium will be impacted in the model, including its connectivity with Carmichael River surface flows, and how if at all the model can be used to provide commentary on environmental values associated with the river and the alluvium.

There is also concern about 5 other bores in Appendix C which are identified as being in the alluvium and may have been used in the model calibration. These bores appear to be in clayey material to the north of the Carmichael River and if they are in an alluvial aquifer it seems likely to be very poorly connected to the Carmichael River alluvium. Of these 5 bores in question 4 are always dry. It needs to be understood if these 5 bores have been used in the calibration process, if so that seems questionable.

Initial heads in Base Case Tertiary and Weathered Zone

Appendix C contains 5 bores identified as being in the Tertiary sediments only. The 4 northern bores have Base Case initial heads of between 3 and 12 m above observed water levels. The fifth bore, just south of Mellaluka Springs has an initial head 13 m lower than the observed water levels.

It is not clear how the initial heads were determined for the Tertiary sediments and it is not clear how those bores in Appendix C identified as monitoring the Tertiary and Joe Joe (composite) are used in the calibration process, i.e. representing which layer?

In the Weathered Zone, Appendix C contains 8 bores identified as being in the Weathered Zone. Three of these bores are always dry and it is not clear if they have been used for calibration purposes. Of the remaining 5 bores the model simulated initial heads for the Base Case are between 7 and 11 m higher than observed water levels. This would appear a poor match.

Initial Heads other geologic units/ other areas

Clematis- There is a generally fair to good match between initial heads and observed water levels.

Dunda Beds – There is a good match between initial heads and observed water levels.

Rewan Formation – There is generally a fair to good match in the upper Rewan between initial heads and observed water levels, particularly good near the Doongmabulla Springs. It is accepted that in parts of the Rewan, connectivity is poor and modelling of that connectivity can be challenging.

Joe Joe – Outside the area north of the river, previously discussed, the match between simulated initial heads and observed water levels is good.

Bandanna – outside the area north of the river, previously discussed, the match between simulated initial heads and observed water levels is fair to good. The exception is adjacent the Doongmabulla Springs and bore RN190229, C19018SP.

To develop steady state contours the bioregional assessment contours have been used (at DES' suggestion) to obtain regional water levels and in particular those off to the west. This appears to have resulted in an over estimation of initial heads at 190229, near Moses springs of 21 m.

The regional Bioregional Assessment contours in the Bandanna are primarily driven in this area by a drill stem test in coal seam gas exploration hole, Shoemaker No.1 (located 3.5 km north-west of 190229). It had an estimated head in the Bandanna of 245 m AHD. Given that the water level in an open monitoring bore (190229) is likely to be more accurate than that of a drill stem test, in a bore not primarily constructed to obtain water levels, it is considered that more weighting should be given to the water level in 190229 than Shoemaker No.1.

Colinlea- outside the area north of the river, previously discussed, the match between simulated initial heads and observed water levels is fair to good.

Ability to model dewatering impacts

The 2022 Annual Groundwater Monitoring report identified the following bores as being impacted from dewatering based on the observed water level trends in the bores.

Based on the calibration hydrographs provided in Appendix C a comparison of observed vs modelled water levels (Base Case) is provided below.

In summary the model base case may be slightly under predicting drawdown in bores in the AB seam, C Seam and D seam, close to the dewatering bores.

It also appears to have some difficulty predicting impacts in bores which are not directly accessing the seams and may be in less permeable interburden above or below the seams. In these instances (eg C006P1 and C834SP) there is evidence to suggest the model is slightly over estimating impacts.

Further from the dewatering the model appears to be predicting similar of slightly higher impacts than observed.

It is also noted that the base case simulated drawdowns are greater in C008P2 than in C007P2 when C008P2 is well west of C007P2 (adjacent a dewatering bore).

Bandanna

Bore Number	RN	Observed max DD (m)	Base case max DD	Simulated Initial head (Base Case) above observed (m)	Comments
C006P1	158062	8	19	10	Located in interburden above C seam. Has possibly led to underpredicted dd
C007P2	158065	30	10	10	AB Seam
C008P2	158067	25	20	10	AB Seam. Problem here in that more drawdown is predicted in the bore further away from dewatering than C007P2.
C823SP	158100	27	16	11	C seam

C832SP	158104	3	5	-2	C seam
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Colinlea

Bore Number	RN	Observed max DD (m)	Base case max DD	Simulated Initial head above observed (m)	Comments
C006P3R	158063	31	22	8	D Seam
C180112SP	158093	49	21	1	Sand below D seam
C827SP	158102	37	39	9	E Seam
C833SP	158105	5	5	-1	D Seam. Model not picking up differences in 833 and 834, different units different dd but model says the same.
C834SP	158106	2.5	5	0	Clay and siltstone below D seam
C840SP	158107	2	3.5	2	Sand below D seam
C19026SP	190091				Not used in calibration, replaces C007P3
C19029SP	190604				Not used in calibration, replaces C180114SP

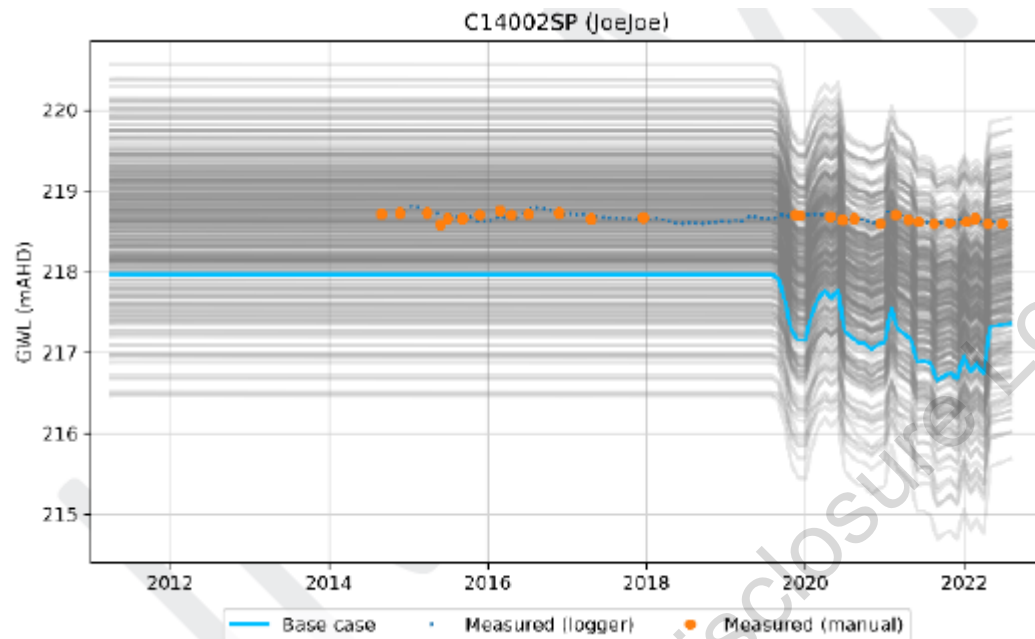
Overpredicting drawdown extent and drawdown

At the southern end of the lease there are predicted drawdowns in the Colinlea from dewatering when there are none observed (C19004SP and C19003SP). There are also predicted drawdowns in the Joe Joe, caused by dewatering, in a number of places in bores (south lease area and down towards Mellaluka Springs) when none had previously been considered to be occurring.

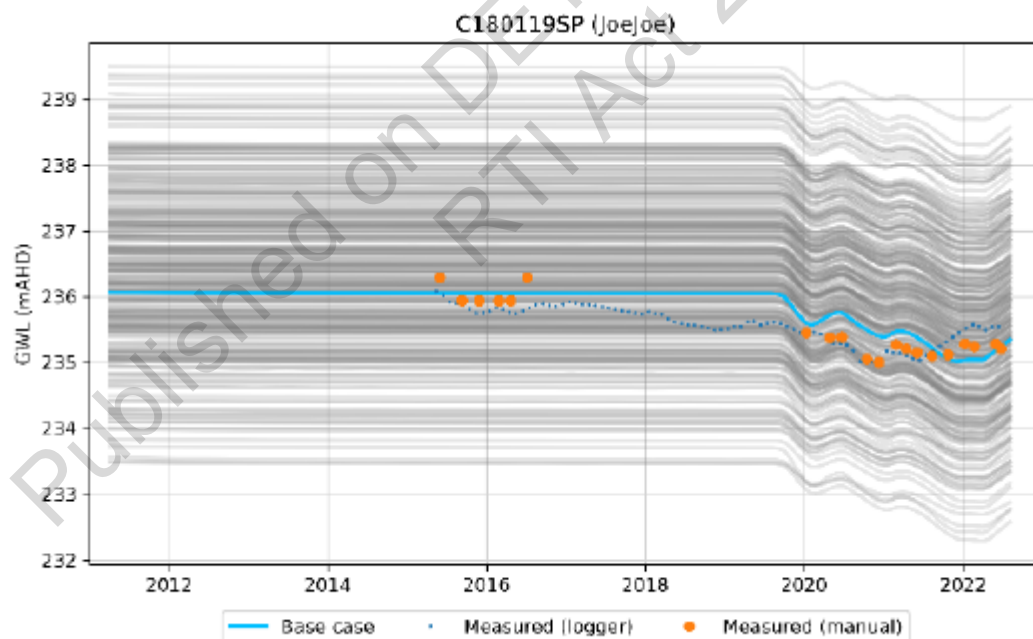
Part of the problem may be that there is some drawdown in some Joe Joe bores to the south caused by local landholder use and the model does not incorporate landholder use so it is trying to replicate the drawdown using dewatering impacts. Perhaps this problem could be addressed by incorporating some landholder use.

The other concern here is the significant increase in predicted impacts in a number of formations including the Joe Joe. In determination of previous groundwater level thresholds in Joe Joe bores adjacent Mellaluka Springs the maximum predicted drawdown had been determined to be less than 1 m. In the new model open cut only scenario, Appendix A in the GMMP Review report, the

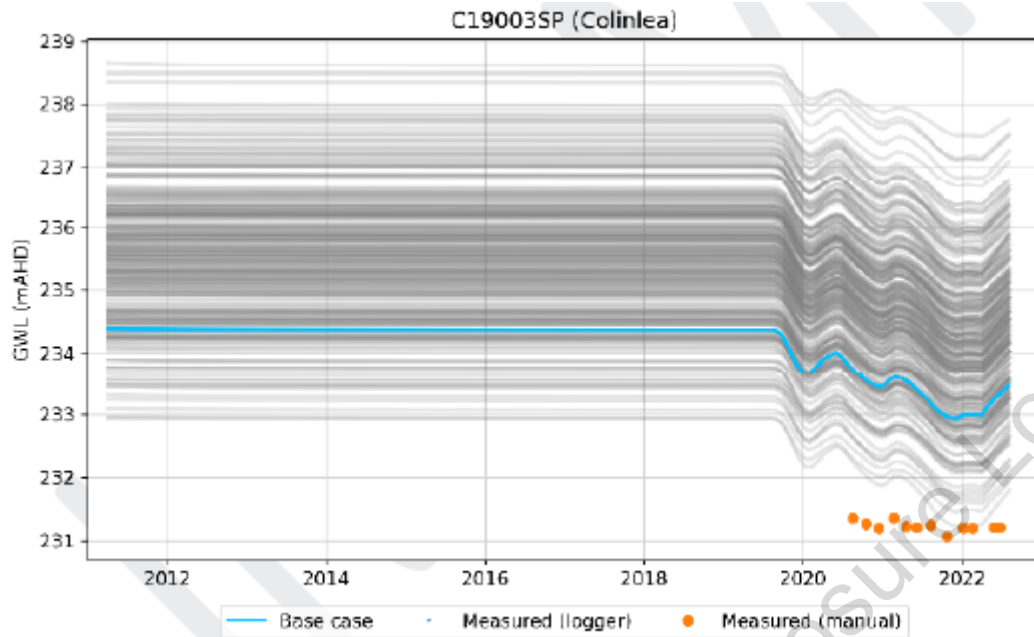
maximum predicted drawdown is now 60 to 80 m in these same Joe Joe bores. Is that realistic or has the model been unduly influence by not including landowner water use in this southern area.



RN165366 Joe Joe bore located south-east of current mining approx. 5 km from nearest dewatering bore. Predicted drawdown from mining when none occurring.



RN158096 Joe Joe bore located 21 km south of the Carmichael River. Some oscillation of observed groundwater levels is occurring and the model is simulating impacts from mining.



RN190228 Colinlea bore located on southern boundary of lease, 15 km south of Carmichael River. No apparent decline in observed groundwater levels and model is simulating impacts from mining.

Calibration Targets

Section 4.1.1 of the draft model report states:

A total of 11,443 history-matching targets were employed. These were subdivided into the following groups:

- *239 hydraulic head targets, grouped by HSU;*
- *11,202 head-change targets, grouped by HSU; and*
- *2 flux targets.*

It is further stated that the weights of the hydraulic head targets were increased to double the relative computational effort towards matching absolute groundwater levels.

However, the number of heads targets vs head change targets is very low and it is not clear if the calibration process may be overly biased towards head change rather than a mixture of head change and absolute heads.

Dewatering Volumes used in modelling

Section 3.5.5 Mining Activities states:

i Production bores

The MODFLOW well (WEL) package is employed to simulate groundwater abstraction from mine dewatering bores. Measured groundwater abstraction for each bore is incorporated in the monthly stress periods in the history-matching period from August 2019 to March 2022 (Table 3.2).

On a number of occasions Bravus and EMM have been asked how they will attribute dewatering volumes to each layer in the model given the dewatering bores typically take water from multiple model layers. DES had been advised that this process would be explained in the model report. It does not appear to have been.

Uncertainty Analysis Presentation of Results

Appendix D provides hydrographs of predicted long term water levels for the Open Cut only scenario.

In the DSC springs the maximum predicted drawdown is about 0.10 m.

The presentation provided by Bravus on 31 January 2023 demonstrated that at an assortment of the DSC springs, in 0% of the predicted model runs the drawdown at these springs exceeded 0.2 m.

However, in section 5.1.1 of the model report, the subject of assessing the likelihood of drawdown, is discussed. Table 5.1, reproduced below provides explanation of the approach.

Table 5.1 Combined numeric, narrative, and visual approach for assessing the likelihood of drawdown

Percentile band (outcomes ranked from small to large)	Colour code	
<P10		It is very unlikely that drawdown exceeds the threshold
P10 to P33		It is unlikely that drawdown exceeds the threshold
P33 to P67		It is as likely as not the drawdown exceeds the threshold
P67 to P90		It is likely that drawdown exceeds the threshold
>P90		It is very likely that drawdown exceeds the threshold

The model report states:

the approach is based on Table 2 of the IESC guidance note on uncertainty analysis (Middlemis and Peeters 2018).

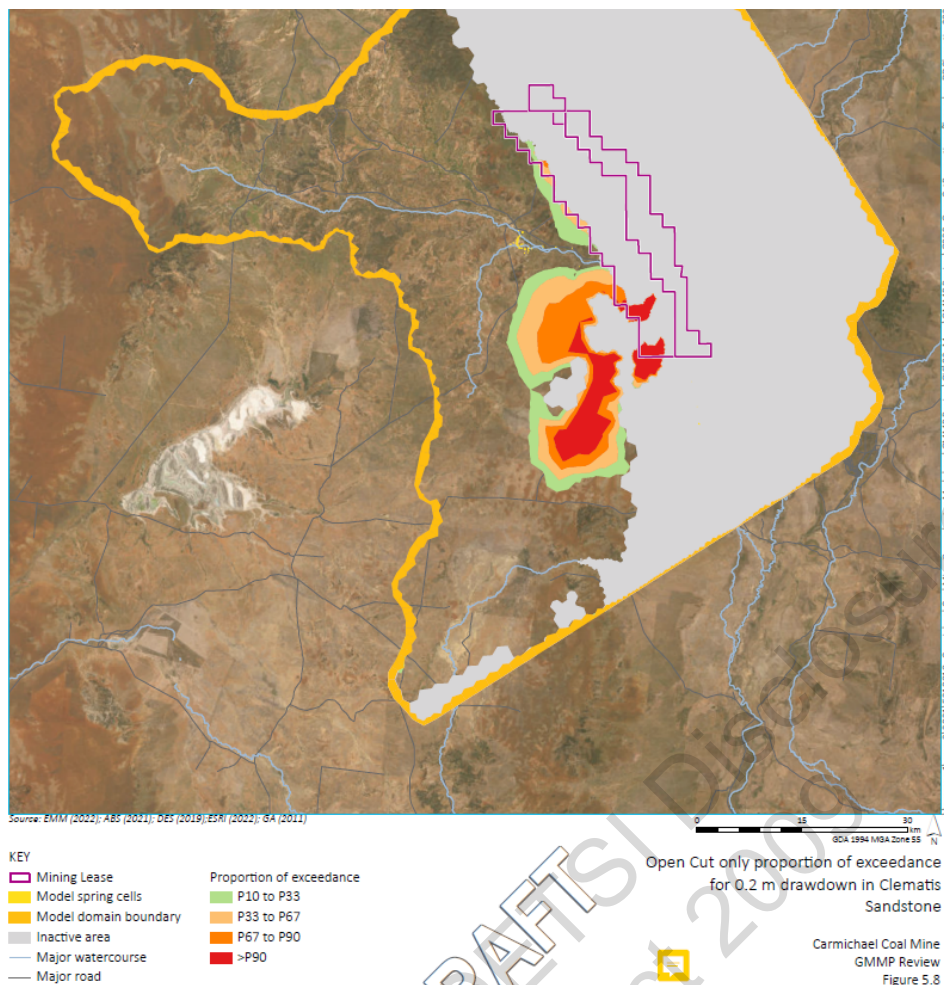
In Figure 5.8, reproduced below, the proportion of exceedance of 0.2 m drawdown (open cut only scenario) is mapped for the P10 to >P90 areas. Less than P10 is not mapped and it is not clear if everywhere else is inferred to be less than P10 or how that is interpreted.

As a result, the model report then states:

Figure 5.8 shows the contour intervals for the likelihood of exceedance of the 0.2 m drawdown threshold in the Clematis Sandstone for the open cut only scenario. The ‘very likely’ region is in the south to southwest of the mine lease and away from sensitive receivers. All DSC springs fall within the ‘very unlikely’ category, meaning that the springs are predicted to be under little risk of experiencing drawdown in breached of the drawdown threshold.

This may just be a different way of presenting the same outcomes but it can be somewhat confusing or misleading to firstly see that none of the uncertainty runs are predicted to exceed a drawdown of 0.2m but then in the text of the report it says that it is very unlikely that drawdown will exceed 0.2m at the springs.

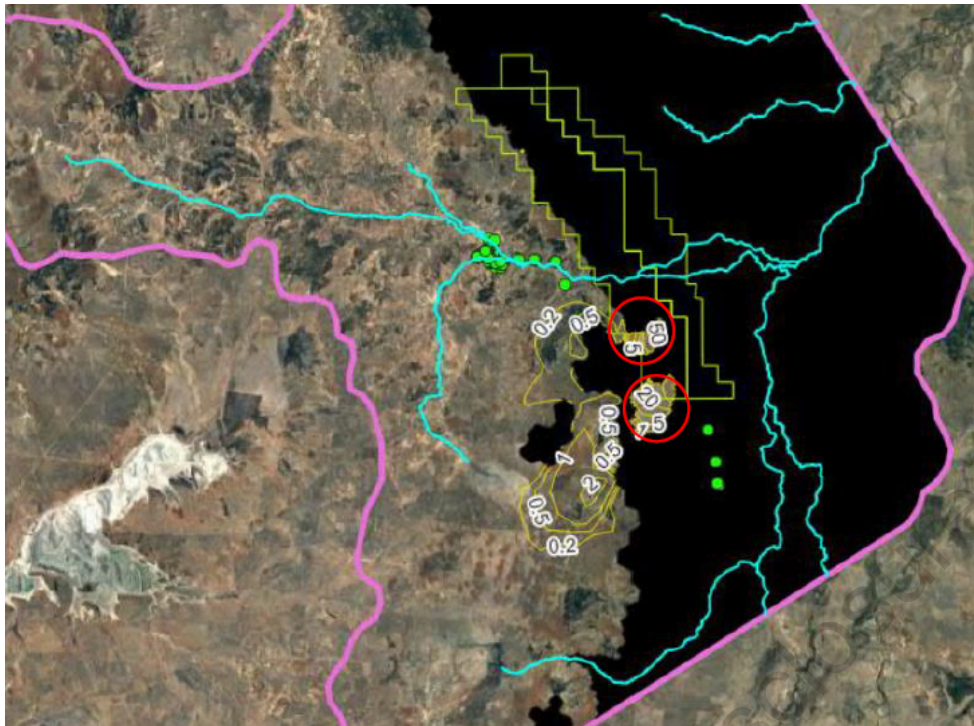
Further advice should be sought on this matter and possibly clarification of how the two pieces of information should be interpreted.



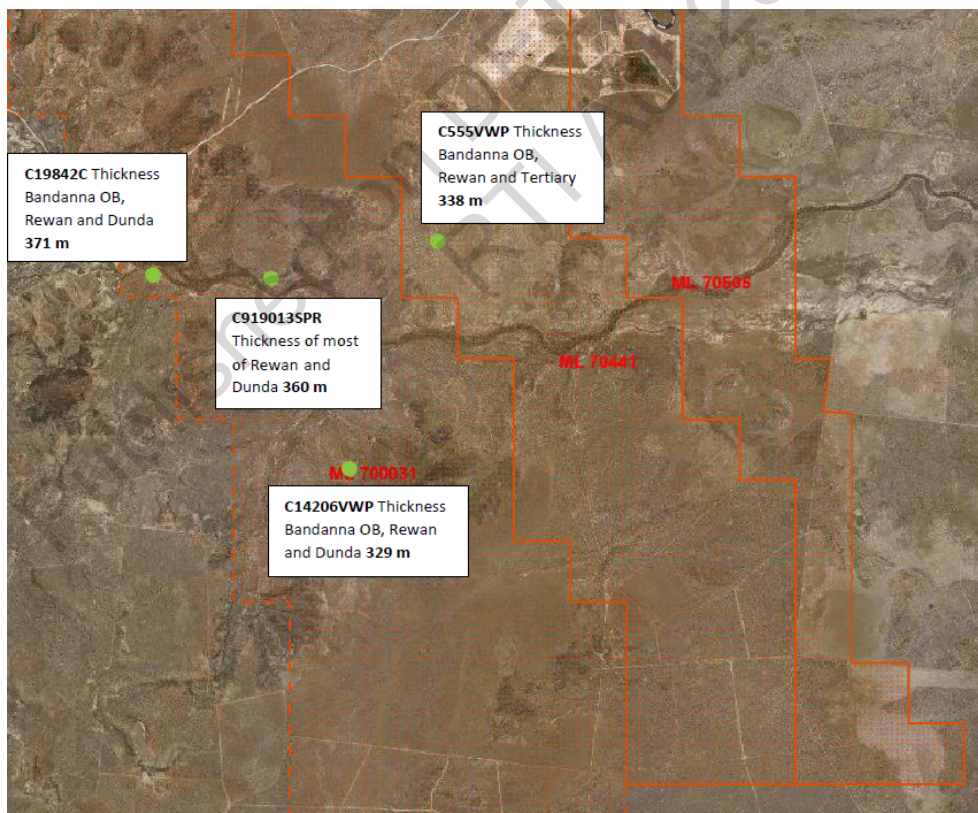
Geology, extent of Clematis and Dunda Beds

There is an area on the south-western edge of the mining lease where the extent of the Clematis Sandstone has been reinterpreted based on the Titus modelled geological layers. Some interpretation has occurred when using the geological layers to update the numerical model layers.

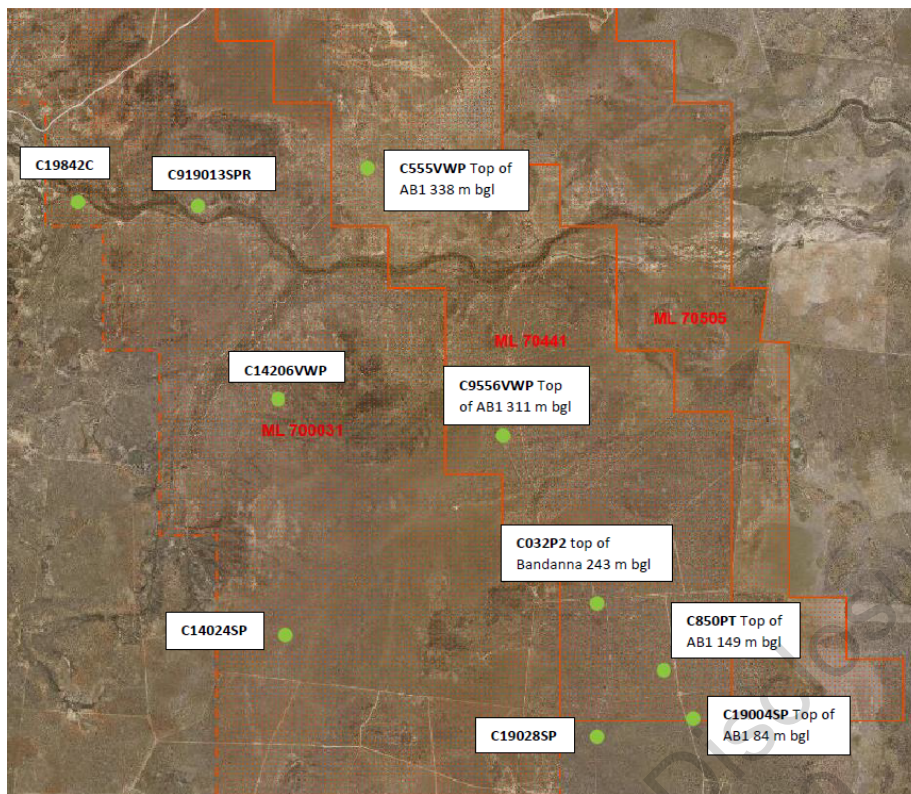
As a result, there are some narrow Clematis extents that are now predicted to intrude into the mining area, where previously they had not. This Clematis mapping was explored further.



The orange circles represent the areas of Clematis Sandstone which are now mapped and modelled as extending into and adjacent the lease area



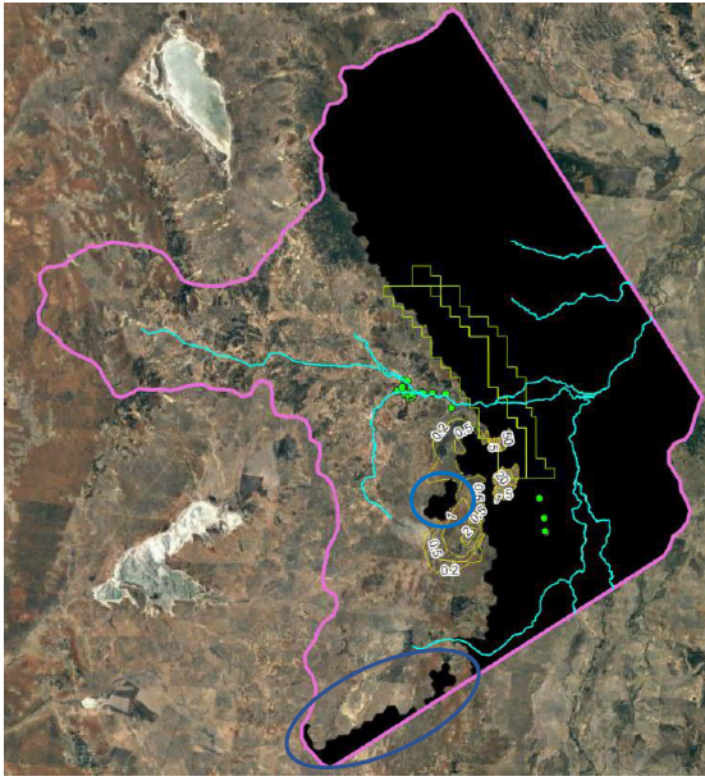
Determining average thickness of the Bandanna overburden (above AB seam) Rewan and Dunda Beds in the area, which is some 330 m in this area.



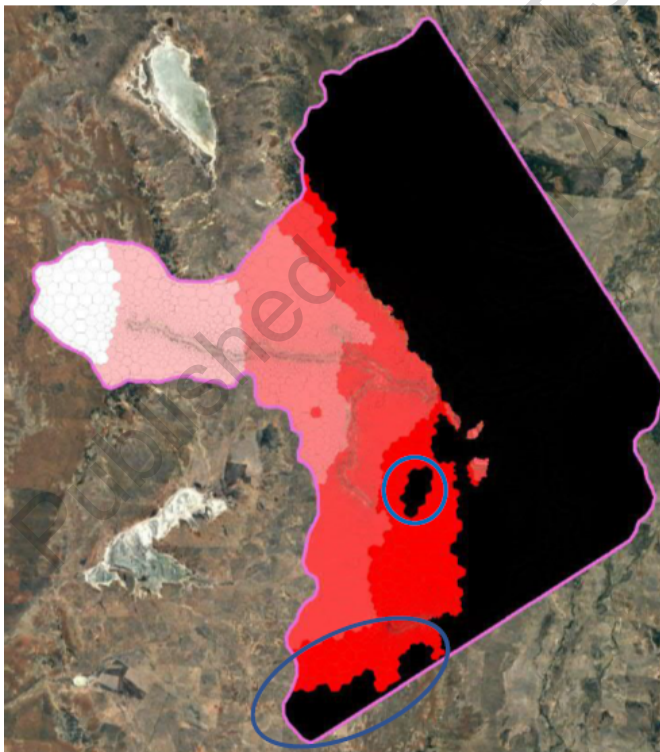
Determining depth to top of AB Seam in the south-western lease area

Based on the average depth of cover above the AB seam and the depth to the AB seam in this area, there appears to be no evidence of Clematis sandstone jutting out into the lease area as has been mapped. That needs review based on actual data.

Other areas of concern with Clematis and Dunda mapping



Clematis



Dunda

The circled areas show areas of apparent 'holes' in the Clematis and Dunda which are not supported by existing mapping available in the area.

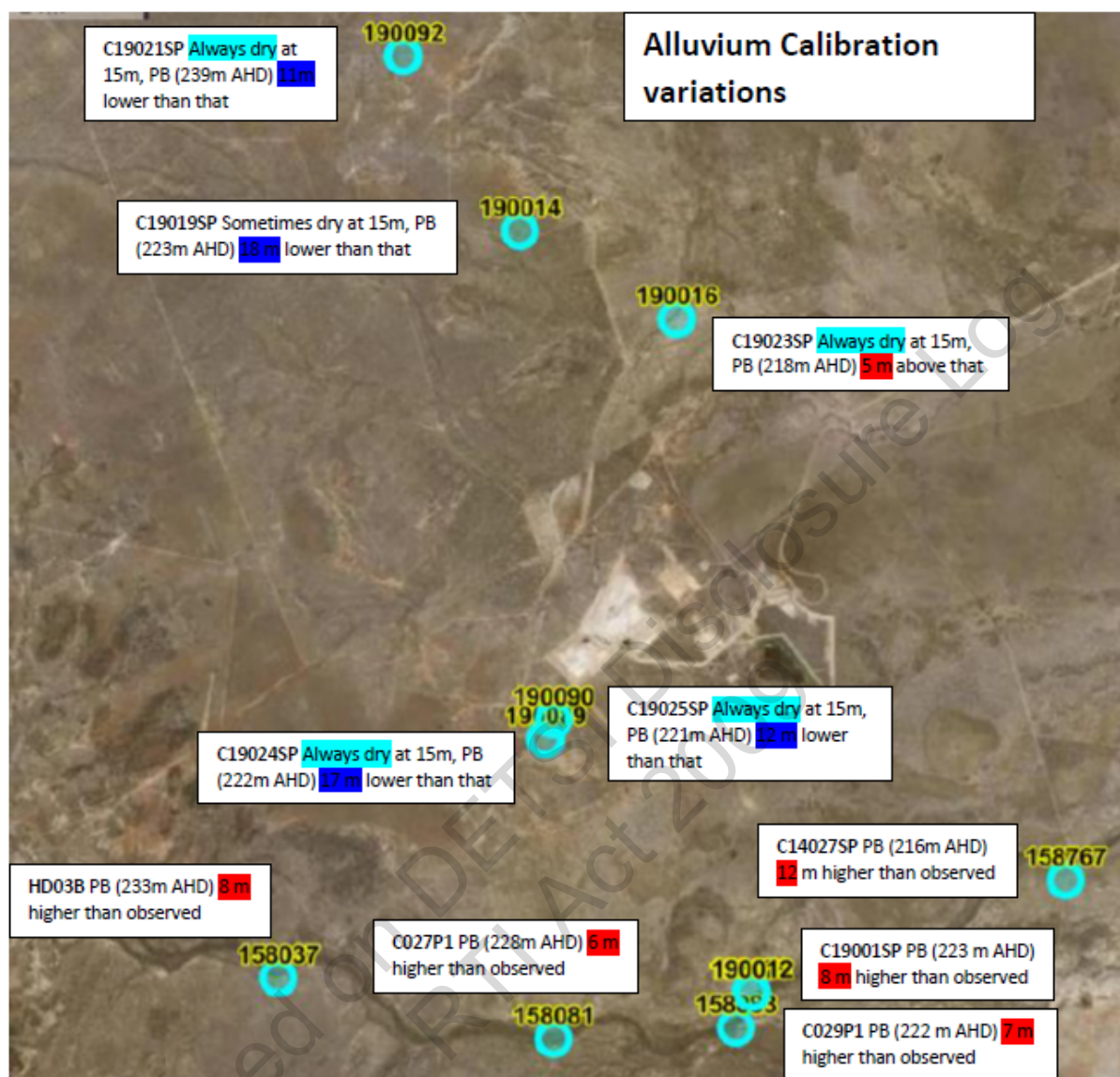
Section 7, Summary and recommendations from the model report states the following:

As noted by Murray (2022), tying in the local Rewan Research model to the Bioregional assessment model highlighted some very significant mismatches and worrying errors. Murray recommended that a full review of the broader Bio-regional assessment model is warranted.

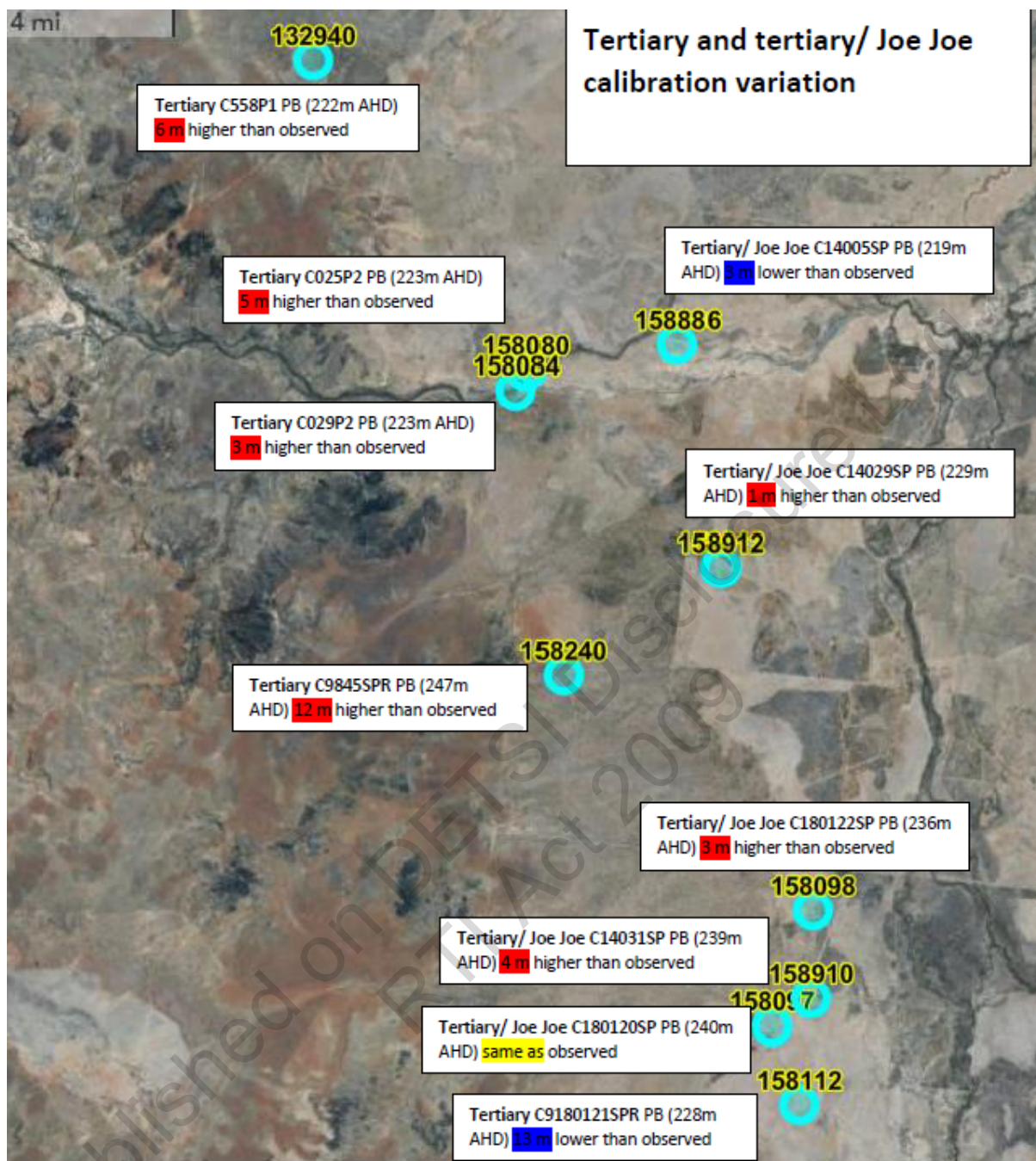
This appears to be the problem with the holes identified in the maps above. It is noted that there is now a lot of additional data in this area including from CSG holes and it is considered that a more realistic representation of the Clematis extent could be provided in the model area than has been presented.

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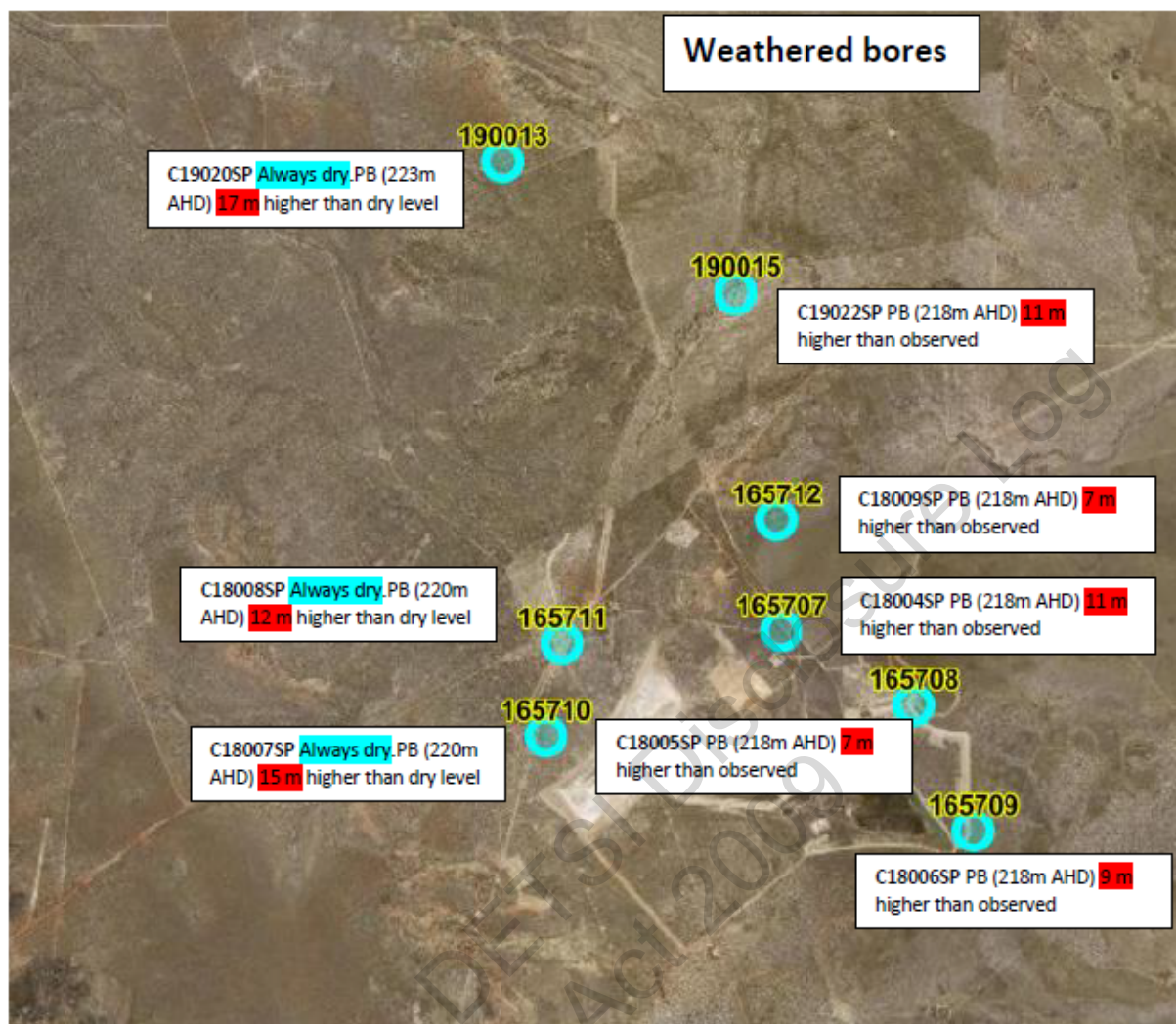
Appendix A

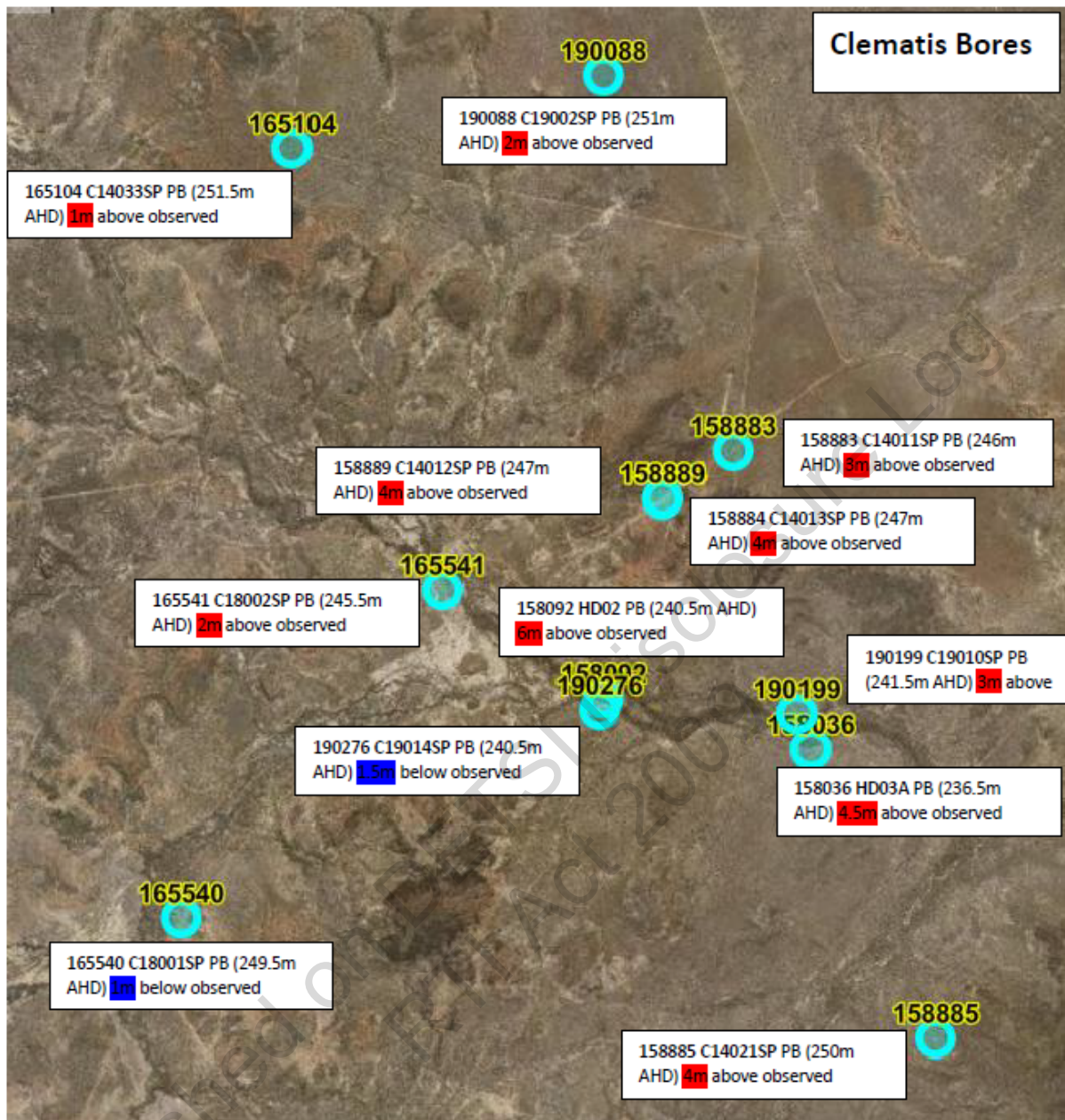


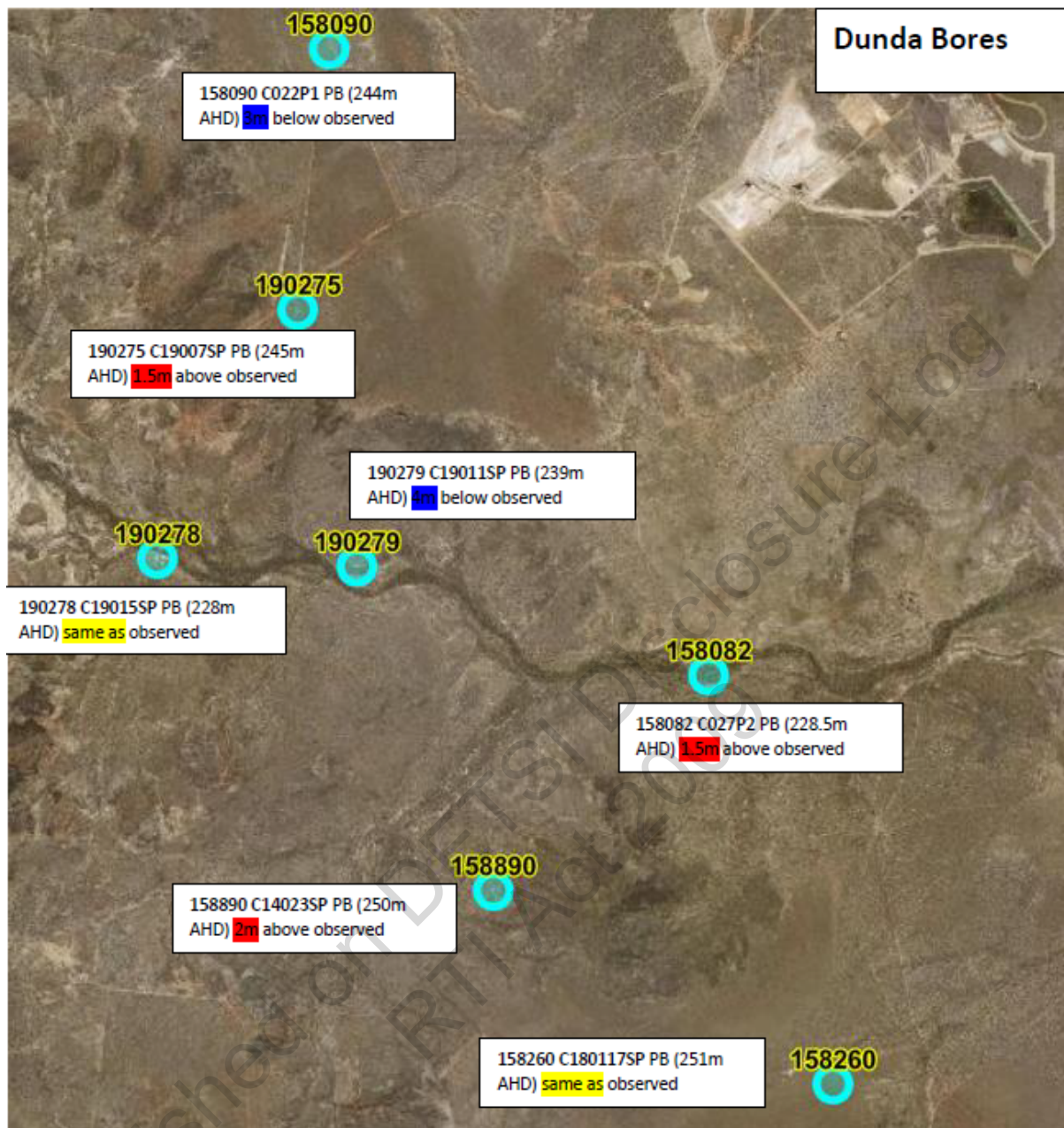
PB – Predicted Base Case initial head

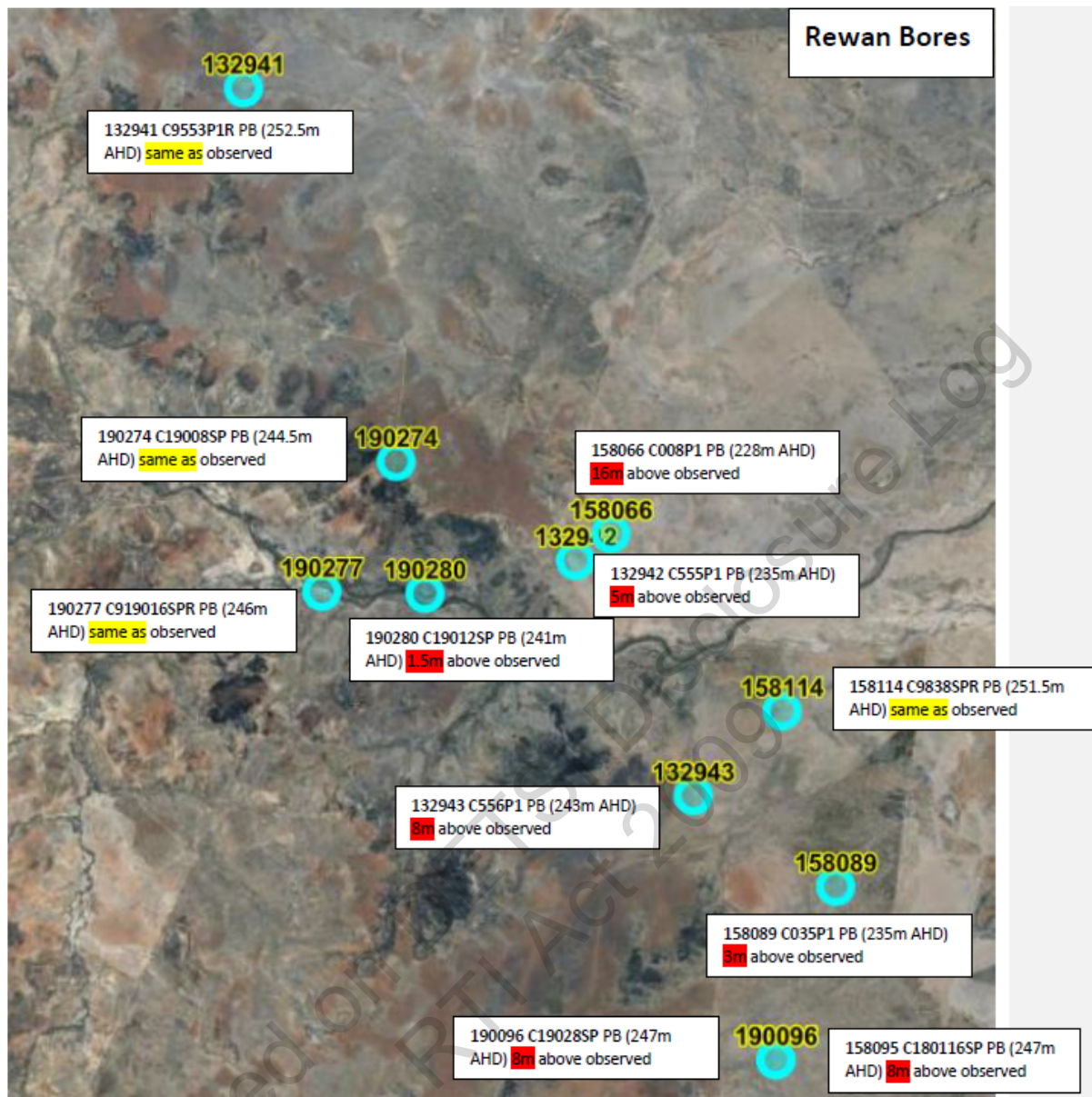


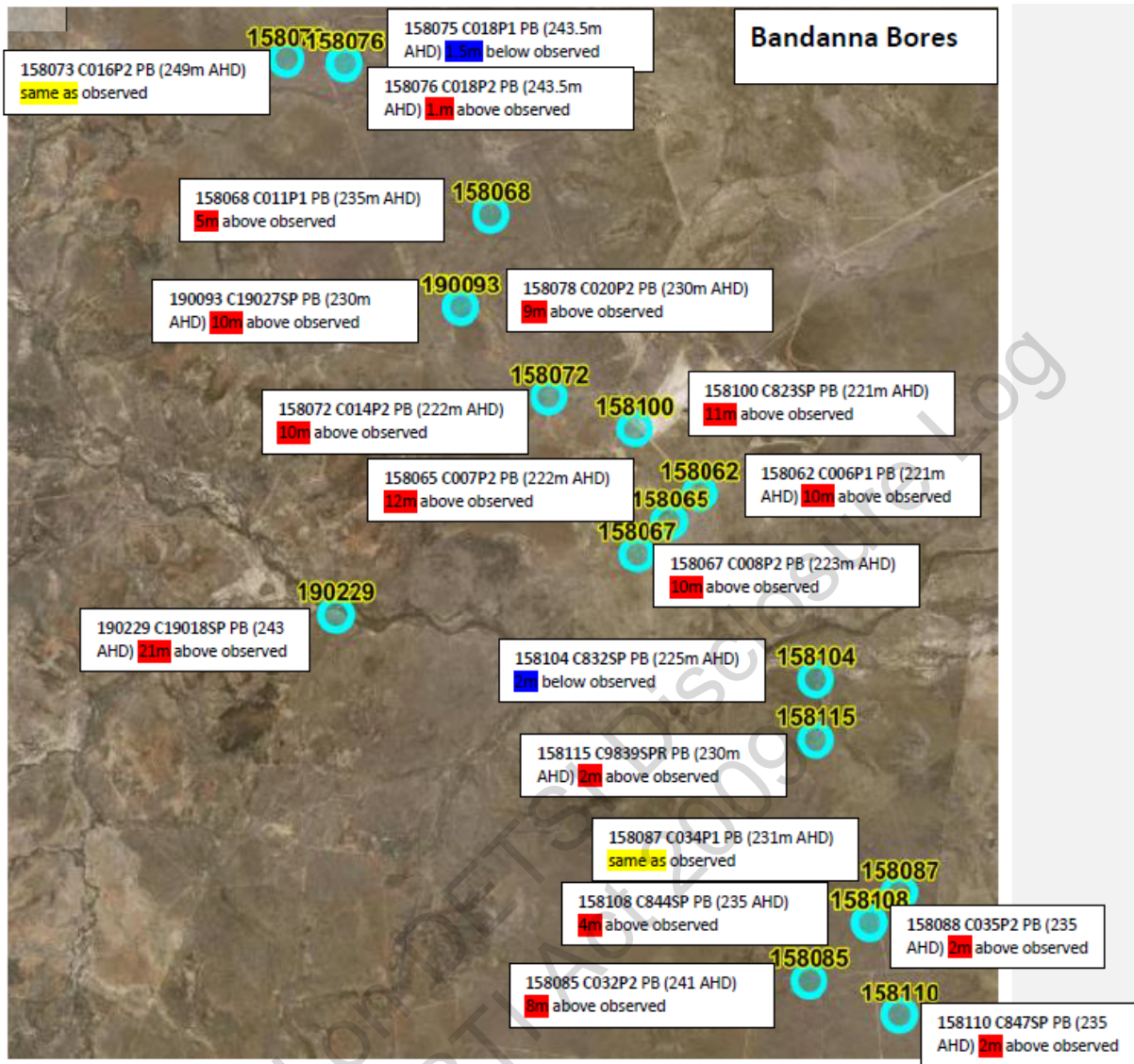
Two sets of bores, those representing the Tertiary Sediments and those accessing both Tertiary and Joe Joe described as composite in Appendix C and not clear what layer they represent in the model

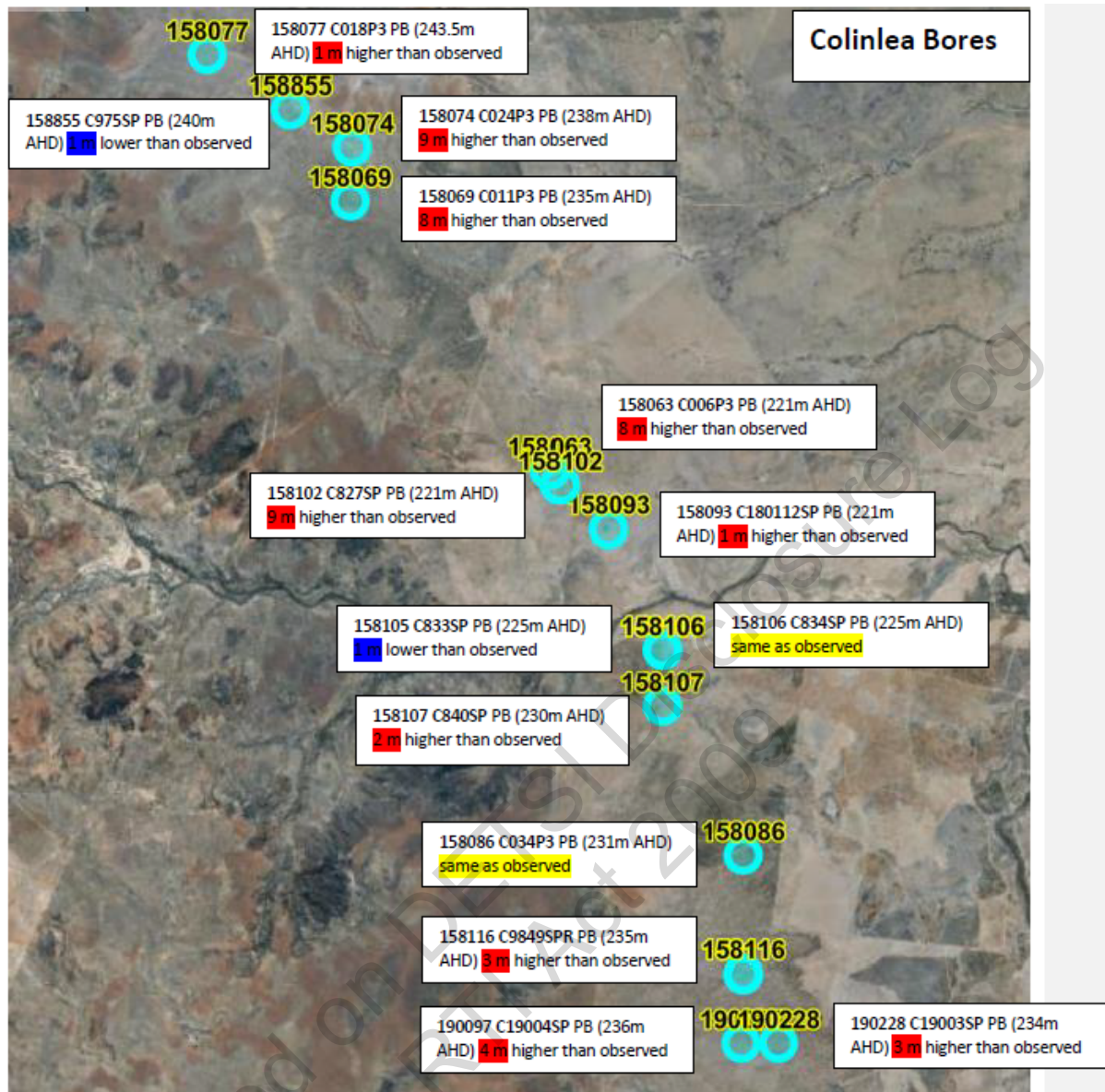




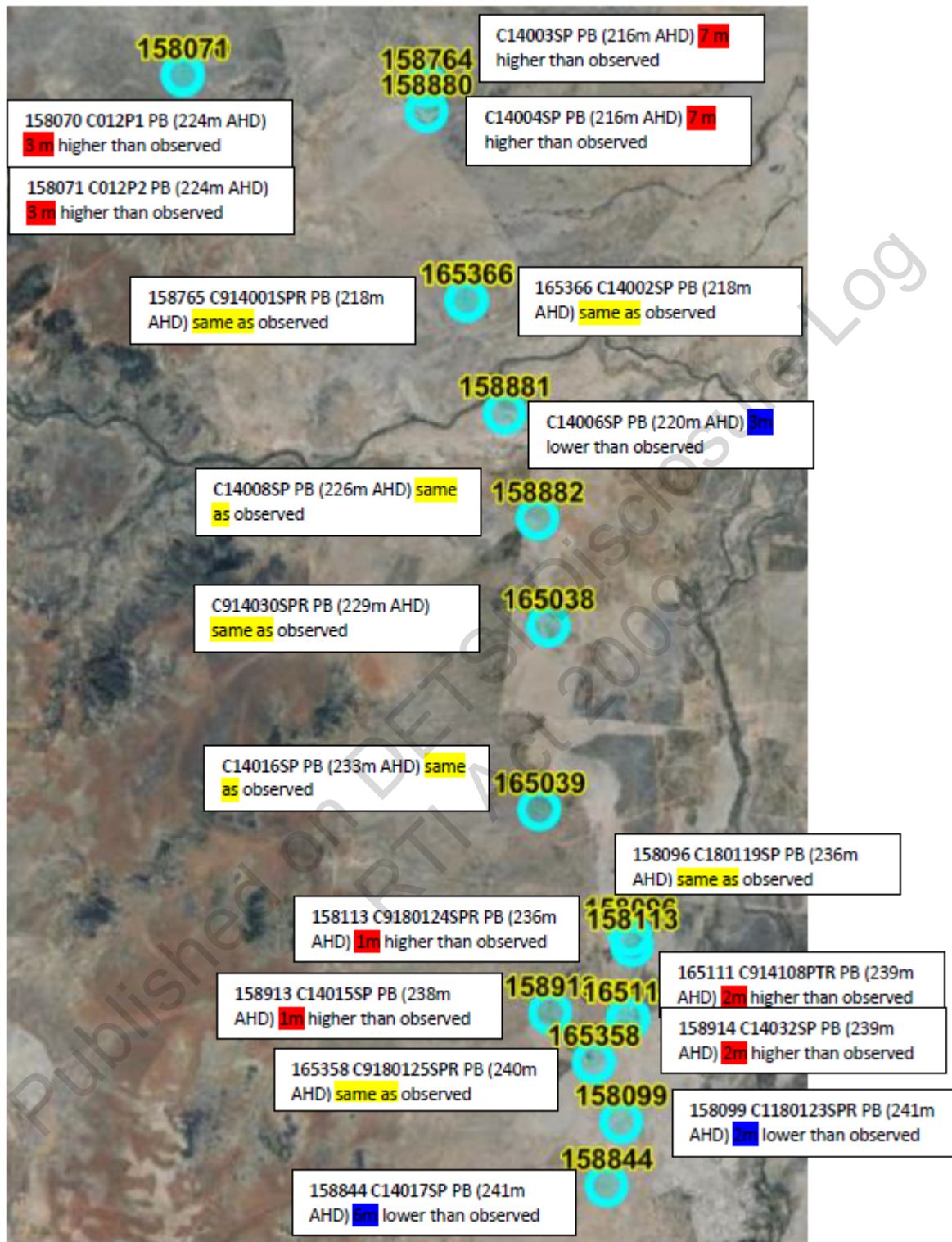








Joe Joe Bores



Section	Review GMMP finding	DES recommendation
3.2.1 Groundwater Monitoring Locations	<p>Three sites have been selected for additional Colinlea Sandstone (two bores) and Bandanna Formation (one bore) monitoring bores.</p>	<p>This proposal is supported and it is considered that the additional sites are critical.</p> <p>However, it is considered that even with these additional monitoring bores there will still be deficiencies in the proposed network monitoring these formations. This issues and the proposed additional locations are discussed as follows:</p> <p>Colinlea Sandstone In order to better understand the propagation of drawdown from the mine towards the Doongmabulla Springs there should also be a Colinlea Sandstone monitoring bore on the western lease boundary in a location that won't be mined out. There should also be a standpipe bore in the area of C19031VWP as given the unreliability of the existing VWP bores there can be no guarantee that data from this VWP is representative of the Colinlea Sandstone.</p> <p>Bandanna Formation Similarly, there should be a Bandanna Formation monitoring bore on the western lease boundary in a location that won't be mined out.</p> <p>Colinlea Sandstone and Bandanna Formation There is a proposal in section 3.2.1 to drill additional Colinlea Sandstone and Bandanna Formation monitoring bores south of the lease in the direction of Mellaluka Springs. This is supported but the proposal to treat this as a low priority, and delay until mining progresses south and impacts are noted in C19003SP and C19004SP, is not supported.</p> <p>Given the issues with local landholder use potentially impacting water levels in this area and the challenges in unpacking which stress is causing impact, the sooner baseline data is available from the proposed Colinlea Sandstone and Bandanna Formation bores in this area, the better.</p>

		<p>There are also concerns in both the Colinlea Sandstone and Bandanna Formation that there are sizeable gaps in the network in critical areas in the southern part of the lease area.</p> <p>In the Bandanna Formation there is a gap between C9839SPR (at 0.34 m/yr (table 6.6) almost considered impacted) and C034P1 which is some 5.6 km south of C9839SPR. Tracking this impact south will therefore soon become difficult.</p> <p>In the Colinlea Sandstone there is a gap between C840SP (most southerly monitoring bore considered impacted 0.47 m/yr (table 6.7)) and C034P3 which is some 5.8 km south of C840SP. Tracking this impact south will therefore also soon become difficult.</p> <p>Additionally, figure 3.1 shows Bandanna bore 823SP as an existing monitoring bore but it was mined out recently. This figure needs to be amended to provide an accurate understanding of the existing monitoring bores.</p>
3.2.2 Groundwater quality trigger levels	In this section the review states: <i>The contaminant limits in the GMMP should be updated using the same dataset as was used to develop the updated trigger values for consistency.</i>	It is recommended that the GMMP has consistent terminology with the environmental authority.
3.2.3 Groundwater level thresholds	This section discusses reassessment of groundwater level thresholds where logger cable lengths have been remeasured in some artesian bores and adjustments made to historical logger data. This work is supported.	<p>However, there are other artesian bores where there still appear to be differences between the manually measured water level elevations and the logger data. A list of these bores has been provided below. How are these bores going to be investigated to determine the cause of this variation?</p> <p>Clematis Sandstone C18001SP C19014SP HD03A Dunda Beds C19011SP C19015SP Rewan Formation C19016SP Joe Joe C14017SP</p>

3.3 Review of the validity of the groundwater monitoring program against the revised model predictions required under Condition E9	<p>The heading in this section appears to be linked as much to E7(d) as it is to E9. It is recommended that E7(d) also be referenced. Noting that in Table 2.1 when discussing E7(d) reference is made to section 3.3 as to where the requirement is addressed.</p> <p>Otherwise, the wording in this section indicates that the review of the numerical groundwater model is to be completed by 10 October 2022 and a model review report issued before 10 January 2023.</p>	<p>There is no discussion as to when Bravus would be providing a review of the validity of the groundwater monitoring program against the revised model predictions. This GMMP review must identify when this will occur.</p>
GMMP Commitment 2 - Augment the existing groundwater monitoring network over time to enable ongoing groundwater impact evaluations	<p>Previous concerns raised in reference to section 3.2.1 and the issue of adequate monitoring bores in the Bandanna Formation and Colinslea Sandstone, also apply here and should be included/discussed here.</p>	<p>The low reliability of the groundwater data coming from the VWPs identified by both DES and the 2022 annual groundwater monitoring report must be discussed here and addressed as to the impacts this has on the reliability of the longer-term network and how the issue might be addressed.</p>
GMMP Commitment 3 - Maintain and decommission of bores, according to industry standards, to ensure the management of groundwater resources and the collection of representative groundwater monitoring data	<p>Similarly, there is concern that the data coming from the VWPs is not representative of the aquifers.</p>	<p>The issue being that DES does not consider that the VWP's are being maintained to collect representative groundwater monitoring data. This issue must be discussed and addressed.</p>
GMMP Commitment 5 - Detail all automatic water level	<p>As discussed in response to section 3.2.3 there may still be</p>	<p>These must be investigated.</p>

loggers (model, setting, and setting information), including the depth of installation within the artesian bore headworks	some artesian bores where cable lengths may still be causing a discrepancy.	
GMMP Commitment 8 - Monitor the recently installed (2018) shallow seepage groundwater monitoring bores, prior to construction of mine affected water and waste storage facilities	The review report identifies the six bores and states that water quality data has been collected for all six bores but then says that two have been dry since they were drilled.	This should be reworded to say water quality has been collected from four only because the other two are dry.
GMMP10 – Boundary Bores	Four of the five bores are dry.	Provide a discussion and a way forward.
GMMP 14 - Additional bores monitoring the Dunda Beds, Rewan Formation, and Permian Betts Creek Beds (which includes the Bandanna Formation and Colinlea Sandstone) will be installed within one year of commencement of mining operations at three locations co-located as far as practicable within 500 m of existing Clematis Sandstone monitoring points as follows: HD02, HD03A, and C14011SP including one bore within the vicinity of the Doongmabulla Springs Complex	The status reported in the review report is that this commitment has been met.	<p>This does not appear to have been achieved as there are no Permian bores at two of the sites. Please review the status and discuss.</p> <p>HD02 area (RN158092) C19014SP (Clematis) (190276) C19015SP (Dunda) (192078) C919016SPR (Rewan) (190277) C19018SP (Bandanna) (190229) C19031PT (VWP) (Colinlea) (190605)</p> <p>HD03A area (RN158036) C19010SP (Clematis) (190199) C19011SP (Dunda) (190279) C19012SP (Rewan Shallow) (190280) C919013SPR (Rewan Deep) (190607)</p> <p>C14011SP area (RN158883) C19007SP (Dunda) (190275) C19008SP (Shallow Rewan) (190274) C19009SP (Deep Rewan) (190198)</p>
GMMP Commitment 16 - For all new bores, to be drilled after	All new bores will be assessed against the water	The review report states that water quality triggers for new bores will be developed in consultation with DES when at least eight water

<p>the compilation of the initial GMMP, a minimum of 12 datasets over 24 months, will be collected prior to developing groundwater level thresholds and water quality triggers for discussion with DES for inclusion in future iterations of the GMMP</p>	<p>quality triggers developed for each hydrostratigraphic unit until (and if required) bore specific triggers are developed</p> <ul style="list-style-type: none"> - All new bores will be installed as soon as possible so as to compile additional groundwater data to inform the conceptual model and the refinement of the model as required in Condition E4a and E6 - Any consideration of revising the groundwater level thresholds, based on new data acquired, must assess the potential impacts of the revised groundwater level thresholds on GDEs. 	<p>quality results have been collected for each bore. This appears to contradict the commitment which states 12 datasets. This should be reviewed and explained.</p> <p>This commitment also appears to contradict commitment 18 where it appears to indicate that a minimum of 8 measurements can be used to develop water quality triggers.</p> <p>DES recommends 12 datasets.</p>
<p>GMMP Commitment 19 - Assess groundwater, surface water, and springs using isotope tracers to aid in the assessment of water quality</p>	<p>The review states: Status: Compliant. <i>Bravus commenced assessment of groundwater, surface water, and springs using major elements, trace elements and isotope</i></p>	<p>There was significant discussion of this issue at the draft conceptualisation report stage in early 2022 between DES and Bravus. There was concern by DES that there is no indication as to which springs were sampled. As previously advised DES is concerned that the varying water quality across the springs is not being adequately compared to that in the spears and that in the</p>

results and groundwater conceptualisation	<i>tracers to aid in the assessment of water quality results and groundwater conceptualisation in 2018/2019 and again in February 2021. Results of the isotope tracers are included in EMM (2021b) and were discussed in the previous GMMP review (EMM 2021a). No additional studies have since been undertaken.</i>	bores in the various aquifers. It was considered that a more detailed approach looking at one spring at a time would provide more useful results ensuring the source of spring groups can be confirmed. Bravus responded to this with some additional information, but this will need to go in the updated conceptualisation report. There needs to be discussion as to how this has been dealt with in the updated conceptualisation report.
GMMP Commitment 23 - Include in the review of the GMMP an assessment of groundwater level and water quality data, and the suitability of the monitoring network, as per Condition E5. The GMMP will be reviewed by a suitably qualified person with a report on the outcome of the review to the administering authority by 1st July 2021. After the initial review, the review must be completed within three months of the second anniversary date of commencing box cut excavation and every 5 years following	As with the response to commitment 3 there are issues with the reliability of the data from the VWP that are not dealt with in the response to this commitment.	The assessment in the annual groundwater monitoring report of the water level data from these bores being of low reliability should be included in discussions.
GMMP Commitment 24 - The results of research plans, inclusive of the GAB Springs Research Plan and Rewan	Following the DES review of the draft conceptualisation report in April 2022, DES requested copies of all available research	Provide copies of all relevant results and research plans inclusive of GAB Springs Research Plan and Rewan Formation Connectivity Research Plan to DES.

<p>Formation Connectivity Research Plan, will be incorporated into the next iterations of the numerical model review and GMMP (within two years of box cut and every five years after that)</p>	<p>plans reports. No additional research plan reports have been provided to DES since that time. When will this occur.</p>	
<p>GMMP Commitment 25 - Two existing surface water flow monitoring stations CAR04 and CAR01 will be serviced to make them operational. An additional two stream flow gauging stations, one between the Doongmabulla Springs and the western edge of the mining lease, the other downstream of the eastern edge of the mining lease and upstream of the Belyando River confluence, will be installed. These surface water monitoring locations will allow for identification of impacts on the Carmichael River and associated GDEs</p>	<p>There is some confusion with the reference to the additional stream flow gauging station between the Doongmabulla springs and the western edge of the mining lease. In the response to this GMMP commitment it is called Doongmabulla station.</p>	<p>However, in section 3.4.42 it seems to be referred to as Moray West. There needs to be clarification and consistency.</p>
<p>GMMP Commitment 26 - Adani commits to incorporate the following in the groundwater model re-run: (Not copied in full here).</p>	<p>The review report states: Status: Compliant. <i>In accordance with EA Condition E9, EMM is currently undertaking a review of the numerical groundwater model to be completed by 10 October 2022, with the model review report to be issued before 10 January 2023. The issues raised in</i></p>	<p>The report notes the status as compliant however DES cannot accept that status until the model report has been reviewed and approved.</p>

	GMMP commitment #26 will be addressed in the model review report.	
<p>GMMP Commitment 29 - The GMMP review will be conducted by 1 July 2021 (or any other time frame as agreed with DES so as to align the GMMP review and model re-run to happen concurrently). The revised GMMP will include statistical analysis of hydrochemistry and groundwater quality data</p>	<p>The next iteration of the GMMP (after 2 years of commencement of box cut excavation) will provide piper plots of the major ions for all hydrostratigraphic units included in the EA Conditions (Condition E3a), representative DSC springs, and the Carmichael River surface water</p> <p>- Contaminant triggers and limits will be updated when additional statistically sufficient pre- operational hydrochemistry data are collected. It is noted that several monitoring bores do not currently have the required number of analyses to calculate baseline trigger values and are using generic triggers derived from the ANZECC guidelines or average of bore specific data. Additional hydrochemistry results, allowing for the revision of trigger values, will be conducted according to the</p>	<p>It is noted that the EA no longer refers to contaminant triggers or limits. It uses the term water quality trigger levels. It would appear that a recommendation of the GMMP review should be to update the wording in this commitment to be consistent with EA wording.</p> <p>Additionally in the review in response to this commitment it states: <i>It is recommended that contaminant limits be updated using the same dataset that was used to derive the updated trigger levels. These updated contaminant limits are presented in Appendix F and should be included in the next iteration of the GMMP.</i> Appendix F should be reviewed. If appropriate the heading in Appendix F may need changing from revised contaminant limits to water quality trigger levels.</p>

	<p>approach detailed in Section 5.4.</p> <p>- During GMMP review and groundwater model re-run consideration of potential impacts to relevant GDE's will be included when considering revision of trigger values.</p>	
<p>GMMP Commitment 30 - Investigate all groundwater-based complaints and maintain a complaint register. The register will be made available to the regulating authority upon request.</p>	<p>The response here is: Status: Compliant. <i>Bravus will maintain a compliant register for the life of the project and will be made available to the regulating authority upon request.</i></p>	<p>However, it should also be clarified if any complaints have yet been received.</p>
<p>GMMP Commitment 36 - Should groundwater monitoring indicate exceedance of any or all of the groundwater level thresholds and / or water quality trigger levels then DES will be notified via WaTERS and an investigation will be instigated and the investigation report will be made available to the administering authority within the time specified in EA conditions E10 and E12 for groundwater quality trigger exceedances and E13 and E14 for groundwater threshold</p>	<p>It would seem that these EA conditions referenced in this commitment are no longer accurate (perhaps because of a change to the EA).</p>	<p>This report should therefore recommend a change to the wording in this commitment in line with the current EA. At the moment it does not.</p>

level exceedances respectively.		
GMMP Commitment 38 - Should any or all the groundwater level impact thresholds be realised, through the assessment of groundwater monitoring data and comparison to model predictions, then an appropriately qualified person will complete an investigation into the potential for environmental harm (MSES and MNES) and will provide a written report to the regulator as per the conditions. In the event of exceedances of threshold levels on MNES Adani will take the following actions:	<p>Perhaps the wording of this commitment should be reviewed.</p> <p>What does 'groundwater level impact thresholds realised' mean.</p>	<p>Does it mean that thresholds have been exceeded and mining found to be the cause? If so should there be a recommendation to amend the wording to make the intent clearer.</p>
GMMP Commitment 40 - Conduct regular groundwater monitoring bore assessments and maintenance (where required) as well as ensuring dry or damaged bores (as a result of mining activities) are decommissioned according to the latest editions of the Minimum Construction Requirements for Water Bores in Australia, 4th Edition (NUDLC, 2020) and the Minimum Standards for the	<p>The report at the moment states:</p> <p>Status: Compliant. <i>Regular groundwater monitoring bore assessments and maintenance will be carried out by the qualified personnel deployed by the monitoring contractor. Bravus has followed the bore construction standards as mentioned above while constructing additional bores.</i></p>	<p>However, the review must provide detail about how Bravus is carrying out regular groundwater monitoring bore assessments and maintenance.</p>

<p>Construction and Reconditioning of Water Bores that Intersect the Sediments of Artesian Basins in Queensland (DNRME, 2017).</p>		
<p>GMMP Commitment 41 - As the proposed threshold values are reliant on predictions from the numerical groundwater model, to be updated within two years of the box cut excavation then every five years subsequently, Adani will compare the actual measured groundwater level data to predicted drawdown to assess the rate of change. In the instance the drawdown rate of the actual data is steeper/ faster than the predicted rate, an investigation will be commenced into the cause of the drawdown rate change.</p>	<p>The response in the review report is: <i>Status: Observed groundwater level data collected to date has been used to calibrate the updated groundwater model which is currently being developed. <u>Discrepancies between actual and predicted drawdown in monitoring bores to date is a focus for transient recalibration efforts to actual pre-mining dewatering stresses.</u> Groundwater drawdown predictions will be updated as part of the updated groundwater model. These updated predictions will be compared against observed water levels during future reporting to assess the rate of change. Investigations will be undertaken in cases where it is found that the actual drawdown exceeds the drawdown predicted by the groundwater model.</i></p>	<p>The point being made here is not clear. It would have been thought that in the current model update there would also be a focus on the stresses occurring during dewatering. The wording should be clarified here.</p>
<p>GMMP Commitment - Springs, GDE and Baseflow Commitments</p>	<p>A commitment within this section is:</p>	<p>It is agreed/ considered that the drilling of C19031VWP and C19018SP (Bandanna standpipe monitoring bore) and C19842C</p>

	<p>Adani will investigate drilling into deeper Permian age units for the purpose of acquiring data for monitoring purposes and to capture information if required under relevant research programs.</p> <p>The response in the report is: Status: Compliant. <i>Bravus installed an additional monitoring bore (C19031SP-VWP) into deeper Permian age units for the purpose of acquiring data for monitoring purposes and to capture information required under relevant research programs.</i></p>	<p>(deep bore providing lithology down to the Colinlea) have partially addressed this commitment.</p> <p>However, there are concerns about the quality of water level data available from C19031VWP and it is noted that commitment 14 to drill monitoring bores into the Permian Betts Creek Beds (Bandanna and Colinlea) at three identified locations adjacent the Doongmabulla Springs, has only partially been met.</p> <p>These issues should be addressed in this response.</p>
<p>DES Recommendation 2 - Increasing trends in groundwater quality may provide early warning of triggers being approached and should be discussed in the GMMP review report</p>	<p>The response to this issue states: <i>Bi-monthly reporting and investigations of water quality trigger exceedances with comparison to changing groundwater levels has been conducted according to EA conditions E12 and E15, under the guidance of the GMMP. A thorough annual review (EMM, 2022b) has also been undertaken according to EA conditions E18 and E19 which review these trends. The trigger exceedances investigations have indicated that variations in water</i></p>	<p>E15 relates to groundwater level thresholds. Please review the response to this recommendation.</p>

	<i>quality are likely to be natural, rather than as a result of site activities.</i>	
DES Recommendation 5 - The GMMP review report should provide piper plots of major ions for all hydrostratigraphic units and recommendations about revisions to the conceptual model (including isotope tracer results).	<p>The review response states: <i>Piper plots of major ions for all hydrostratigraphic units were included in the previous GMMP review which was submitted to DES in June 2021 (EMM 2021a). Updated piper plots for each hydrostratigraphic unit are included in the bi-monthly water quality exceedance reports. A discussion of isotope tracer results collected as part of the GAB Springs Research Plan are included in EMM (2021b). <u>These isotope tracer results have been used to revise the updated conceptualisation report which has previously been submitted to DES (EMM 2022a).</u></i></p>	<p>The underlined response is true, but this was a draft which DES has made comment on. It should be stated in here that an updated version will be provided as part of the model review report prior to 10 Jan 2023. There remain concerns about whether enough information is provided on the individual springs.</p>
DES Recommendation 6 - Detail isotope tracer studies used to characterise the groundwater dependent ecosystems		DES has the same concern here as stated in regard to DES recommendation 5.
Section 4 GMMP review recommendations	<p>The review states: <i>An additional monitoring bore within Colinlea Sandstone between C19026SP and C19031VWP to track future propagation of dewatering</i></p>	<p>This location is supported, but problems remain. There should also be a Colinlea monitoring bore on the western lease boundary in a location that won't be mined out. There should also be a standpipe bore in the area of C19031VWP given the unreliability of the VWP bores there can be no guarantee that data from this VWP is representative of the Colinlea.</p>

	<p><i>impacts in the Colinlea Sandstone between mining and the DSC. It is recommended that this bore be installed adjacent to existing Clematis Sandstone bore C14012SP/C14013SP.</i></p>	
	<p>The review also states: <i>An additional monitoring bore with Bandanna Formation between C008P2 and C19018SP to track future propagation of dewatering impacts in the Bandanna Formation between mining and the DSC. It is recommended that this bore be installed adjacent to existing Clematis Sandstone bore C14012SP/C14013SP.</i></p>	<p>This location is supported but there should also be a Bandanna monitoring bore on the western lease boundary in a location that won't be mined out.</p>
	<p>The review states: <i>Additional monitoring bores within Bandanna Formation and Colinlea Sandstone in the vicinity of Mellaluka Springs to allow for detection of dewatering impacts near Mellaluka Springs and to improve the understanding of any connection between the Colinlea Sandstone and the Tertiary sediments and Joe Joe Formation. Installation of additional bores between the mining lease and Mellaluka Springs is considered low priority</i></p>	<p>Some additional information on timing would be helpful. Given the issues with local landholder use potentially impacting water levels in this area and the challenges in the unpacking of what stress is causing impact, the sooner baseline data is available from the proposed Colinlea and Bandanna bores, the better.</p> <p>Additionally, the additional drilling of monitoring bores are still required under commitment 14 should be discussed.</p>

	<p><i>and could be delayed until mining progresses south and impacts are noted in C19003SP and C19004SP.</i></p>	
	<p><u>Groundwater Level Thresholds</u> The review states: <i>Reassess baseline average groundwater level elevations and natural fluctuations for each bore incorporating all representative logger data (where available) before commencement of dewatering. Consider further extending baseline period for monitoring bores which have not been impacted by dewatering to date. Currently, only groundwater level data collected up to 2017 is considered in the baseline dataset. Extending the baseline period will allow for better representation of natural climatic variations in water level.</i></p>	<p>In relation to the underlined sentence, it would be helpful to have the predicted existing impacts from the model to compare with the manual assessments already carried out to gain confirmation of which areas are clearly unaffected by mining at this time.</p> <p>There should also be discussion of the low reliability of the water level data from the VWP's and the suitability of these bores to be used as groundwater level threshold bores.</p>
	<p><u>Groundwater quality triggers</u> The review states: <i>The contaminant limits in the GMMP should be updated using the same dataset as was used to develop the updated trigger values for consistency.</i></p>	<p>Refer to water quality trigger value as per EA wording</p>
<p>Review of Annual Monitoring Report – June 2022</p>		

This review focuses specifically on groundwater level monitoring and presentation of metered water use data from the dewatering bores.	
Section	Comments
<u>Section 4 Mine Construction and dewatering</u>	Metered water take – there is only a graph showing combined monthly water use from all 27 bores. DES requires a spreadsheet showing monthly water take from each bore, identified by number. There should also be a map showing the locations of these bores by number. Given that some work has gone into identifying what take is from what geologic unit there should also be a table showing which geologic unit each bore is taking water from.
<u>Review of Section 6 tables</u>	<p>The process of reviewing the water level data in the monitoring bores and VWPs is similar to what occurred in the draft conceptualisation report and is considered a useful exercise to analyse the data and better understand likely dewatering impacts at this point in time.</p> <p>Some comments on the process are provided as follows;</p> <p>In each table, each bore is ranked as having a high, medium or low water level trend reliability. Information is provided in section 6.1 as to what constitutes these various rankings but there are no comments in the tables against the individual bores to provide understanding as to why the data from one bore might be high and another medium. This would be useful particularly in the high and medium categories.</p>
VWPs - General	<p>The water level trend reliability in all the VWPs is treated as low. That assessment is supported. However, the data from most of the VWPs are then used to determine if the probe is impacted by dewatering. Perhaps there should be a footnote that is linked to the VWP assessments of dewatering impact in the tables which says something like, 'given the low reliability of the water level trend, to be used as a guide only'.</p> <p>Where VWPs indicate a difference between pre and during dewatering water level decline of greater than 0.4 m/yr they are investigated further given the low reliability of their water level trend. This approach is supported, although the practice of using data from one low reliability VWP to determine if data from another VWP is likely to be correct, is not supported.</p>
Table 6.8 Joe Joe – C14017SP The report states: <i>Most of the bores show subtle positive linear correlation to climate. Although, C14017SP shows a decreasing trend greater</i>	It is agreed that this water level decline is unlikely to be caused by the dewatering. However, the assessment could be further supported by adding that the nearest Colinlea Sandstone or Bandanna Formation monitoring bore, identified as being impacted by dewatering, is 27 km north of C14017SP (C840SP).

<p><i>than the threshold of 0.4 m (Figure 6.23), this is unlikely to be related to dewatering as the bore is located approximately 33 km from the closest dewatering bore.</i></p>	
<p>Section 8 States; <i>Water level thresholds have been established for 50 monitoring bores and five VWPs. Threshold values are summarised in Table E3 of the EA, and Table 45 of the GMMP (AECOM 2020).</i></p>	<p>This is a quote from AECOM 2020 and therefore is no longer accurate when referencing the table in the latest version of the EA. Water level thresholds are actually now in Table E4 of the EA. This should be explained.</p>
<p>Table 8.1 <i>'Recent adjustment of logger cable lengths indicates that water levels in C14006SP have never actually exceeded the threshold values for this bore.'</i></p>	<p>It appears that the sentence in italics has been cut and pasted from one section of the table to a number of others without changing the bore number. Needs reviewing and adjusting.</p>
<p>Section 9</p>	<p>It is acknowledged that the latest modelling, yet to be completed, will likely provide a better evaluation tool for future annual reporting comparisons. However, for this comparison in this annual report there should be more discussion as to how the SEIS assumptions about mine dewatering/ mining operations compare with what has actually occurred to allow a better understanding of the potential limitations of the process used to present the modelled versus observed drawdown</p>
<p>Section 10 Recommendations <i>Updates to the groundwater model in 2022 should recalibrate to the transient pre-mining dewatering stresses to improve confidence in the modelled</i></p>	<p>The statement in italics seems to be missing some monitoring bore numbers when discussing which bores are impacted. The summary in section 6.13 looks to have the numbers right, perhaps refer to that.</p> <p>The detailed work presented in section 6 of this report demonstrates a number of things. Firstly, it notes that the water level trend reliability in the VWPs is low. DES would agree with this assessment. It is</p>

versus observed drawdowns at locations where trend analysis has revealed actual dewatering impacts occurring. Specifically, this includes bores C827SP, C180112SP, C833SP, C834SP and C840SP in the Colinlea Sandstone and C832SP in the Bandanna Formation.

considered that given this assessment there should be a recommendation as to how this issue will be dealt with in those critical areas where there are no monitoring bores (or only VWP's).

In particular, how will impacts in the target formations (Colinlea Sandstone and Bandanna Formation) be monitored. As DES has previously raised, the area to the west of the dewatering bores, between the dewatering bores and the important Doongmabulla Springs, has poor to non-existent monitoring bore coverage in the target formations.

Figure 6.17 demonstrates reasonable coverage (albeit with some gaps) of monitoring bores in the Bandanna Formation to the north of the dewatering bores (if C19027SP is considered).

To the south there is also reasonable coverage of monitoring bores in the Bandanna although there is a gap between C9839SPR (at 0.34 m/yr almost considered impacted) and C034P1 which is some 5.6 km south of C9839SPR. Tracking this impact south will therefore soon become difficult.

To the west there are no monitoring bores west of C008P2. It is noted that C19018SP has recently been drilled adjacent the Doongmabulla Springs but there is a 10 km gap between C008P2 and C19018SP where there are no Bandanna monitoring bores.

In the Colinlea Sandstone, Figure 6.21 demonstrates reasonable coverage to the south of the dewatering bores although there is a gap between C840SP (most southerly monitoring bore considered impacted) and C034P3 which is some 5.8 km south of C840SP. Tracking this impact south will therefore also soon become difficult.

Figure 6.21 also demonstrates the lack of Colinlea Sandstone monitoring bores adjacent the northern dewatering bores and immediately north of the dewatering bores. C19026SP and C006P3R are adjacent the southern dewatering bores. The closest monitoring bore north of these two monitoring bores shown on Figure 6.21 is C011P3 some 11 km to the north-west.

Figure 6.21 also demonstrates that there are no monitoring bores in the Colinlea Sandstone west of the dewatering bores. Therefore, the work in section 6 is unable to comment on how far west the impacts of dewatering have propagated.

	<p>Given that EA condition E18 requires this report to provide recommendations on changes to the GMMP, it is considered essential that the findings of the water level review in this report are used to provide recommendations to the GMMP about the limitations of the monitoring network as discussed above.</p>
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Coal and Central Queensland Compliance

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CSIRO/GA Questions

Model Report

1. Does the uncertainty analysis presented in the GW Review report meet the IESC guidelines?
2. Does the uncertainty analysis undertaken provide for an acceptable range of potential impacts?
3. Is the modelling undertaken adequate and appropriate to determine the impacts from underground mining on groundwater and in particular the Doongmabulla Springs Complex?
4. Is the use of pilot points justified provide a robust and accurate representation of parameters instead of using one parameter value per layer?
5. Is the model cell size of 500m in the mining areas appropriate especially with respect to identifying longterm impacts from residual voids post mining?
6. Is the modelling of the open cut mining only scenario (parameters used and methodology of the uncertainty analysis) adequate to provide confidence in the predicted impacts to DSC?
7. What additional geological work with respect to the extent of the Clematis and Dundas Beds is required to improve the confidence in the modelling outputs for the optimisation model?
8. Support preliminary DES concerns as presented?
9. Have all the additional works as recommended by CSIRO/GA in 2019 been addressed (whether completed or not) to your satisfaction in particular to support the identification of the source(s) aquifer(s)?

Has enough isotopic work been undertaken to advance our understanding of the source aquifer? Isotopes re. conceptualisation re. Report.

Determining the initial heads from observed. In particular in the alluvium, tertiary and weathered zone
Change in initial heads

9. Has the model adequately addressed the pre mining lows observed north of the Carmichael river in the mining areas (in particular in the Colinlea Sandstone and Bandanna Formation)?
10. What matters must be addressed to the model methodology prior to undertaking an Optimisation model of mining activities to ensure no greater than 0.2m drawdown at DSC?

GMMP report

1. Does CSIRO/GA support the use of GW thresholds for open cut only?
2. Do you support the Bravus proposed additional monitoring bores and locations? Do you support DES recommendations? Any additional?

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