BRAVUS
MINING & RESOURCES

8 February 2023

Cover Note: Updated Numerical Groundwater Model Report

This report contains the outcomes of the review of the Numerical Groundwater Model developed for Carmichael coal mine project. This model is required to be reviewed during 2022 and further on a five-yearly basis into the future in accordance with our Environmental authorisation. During the review the model was developed and run by suitably qualified specialist hydrologists as per the latest Australian groundwater modelling guidelines. The model was subsequently independently peer reviewed and certified by third party expert hydrogeologists and modellers. The model draws on data collected from drilling additional monitoring bores near the Doongmabulla Spring Complex, field surveys, results from onsite and laboratory investigations and data from more than 120 groundwater monitoring bores on the Carmichael Mining Lease and neighbouring landholder properties since the commencement of mining activities in 2020. This is in addition to baseline data collected over the preceding 10 years. Inputs from Geoscience Australia's Bioregional Assessment have been used to update the Conceptual Model and the Water Balance Flow Model SEIS.

More conservative input parameters were selected for prediction of impacts from underground mining in the review, than were used in the model that was published in the Supplementary Environmental Impact Statement. The review assumes geological formations above longwall panels in a proposed future underground mine would be fractured to a distance of 230m, compared to 160m in the Supplementary Environmental Impact Statement.

The key finding of the review is that underground mining at the extremities of the mining lease area that was planned to commence after 2035 may cause drawdown at some locations of 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. It found that this impact may occur post mining some 150 years after the area was mined. The review found open cut mining and much of the planned underground mining would not cause drawdown of more than 0.2m in the springs.

Bravus Mining and Resources is committed to ensuring our operations comply with the various regulatory approvals under which the Carmichael Coal mine operates and to protect communities of species that are dependent on the discharge of groundwater from Doongmabulla springs complex. Therefore, the Carmichael mine plan will be reviewed to ensure that there are no non-complaint adverse future impacts to the Doongmabulla Springs Complex. Updating a mine plan is not uncommon in the mining industry and we are working with independent experts to ensure that our mine plan does not cause adverse future impacts to the Doongmabulla Springs Complex.

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Carmichael Coal Mine

Report No2: Numerical groundwater flow model report

Prepared for Bravus Resources

February 2023

EMM
creating opportunities

Carmichael Coal Mine

Report No.2: Numerical groundwater flow model report

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February 2023

Carmichael Coal Mine

Report No.2: Numerical groundwater flow model report

Bravus Resources

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Version	Date	Prepared by	Approved by	Comments
1	10 October 2022	Tom Neill	Dr Doug Weatherill	Model design
2	8 February 2023	Tom Neill and Joel Georgiou	Dr Doug Weatherill	Updated to include all sections

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This report has been prepared in accordance with the brief provided by Bravus Resources and has relied upon the information collected at the time and under the conditions specified in the report. All findings, conclusions or recommendations contained in the report are based on the aforementioned circumstances. The report is for the use of Bravus Resources and no responsibility will be taken for its use by other parties. Bravus Resources may, at its discretion, use the report to inform regulators and the public.

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Executive Summary

The Carmichael Coal Mine Project involves the design and construction of a thermal coal mine and supporting infrastructure in the north Galilee Basin, approximately 280 km south of Townsville, 300 km west of Mackay and 160 km northwest of Clermont in Central Queensland.

This report has been developed to meet EA Condition E9 which 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 and updated to incorporate groundwater monitoring data and measured mine dewatering volumes from the Groundwater Management and Monitoring Plan (GMMP) in conditions E4 and E5. This is the second groundwater report and builds upon the first report (EMM 2022a) which aimed to capture insights from recent research, investigations, and data gathering to formalise an up-to-date version of the hydrogeological conceptual model (HCM). This revised HCM has informed the design, build, history-matching and prediction processes of the revised numerical groundwater flow model documented in this report.

The updated model constitutes a complete rebuild from the 2013 SEIS model and includes an updated 15-layer representation of the groundwater system based on available geological data and new structural surfaces developed by Southern Highlands Structural Geology. The model update process included history-matching to all available groundwater level and drawdown monitoring data, spanning between April 2011 and April 2022, with the later period including over two and half years of mine dewatering. Updated information developed as part of the Rewan Formation Connectivity Research Plan (RFCRP) and the ongoing 5-year GAB Springs Research Plan (GABSRP) have also been incorporated and include but are not limited to: fault behaviour, aquifer and aquitard parameters, groundwater levels and flow, subsidence-induced fracturing and spring flux estimates and conceptualisation.

Bravus have committed to not cause environmental impacts at the Doongmabulla Spring Complex (DSC). Model history-matching and Type 3 predictive uncertainty analysis employed pilot points and PESTPP-IES to develop 105 accepted parameter realisations for the open cut (OC) only scenario, which has a predicted operational period from April 2022 to December 2076, followed by a 2,000-year post-closure recovery period. Results predict that the OC scenario will not breach the DSC drawdown threshold of 0.2 m for the base case or any of the ensemble of realisations. However, significant modelled drawdown emanates from the open cut F and G pits. This is caused by the assumption that Clematis Sandstone exists in this region, and thus direct dewatering of this unit is occurring, promoting drawdown in this aquifer, which provides artesian flow to the DSC. In addition, vertical hydraulic conductivity of the Rewan Formation at this location is modelled higher than the surrounding areas, arising from the pilot point-based history-matching process. This allows drawdown from the deeper Permian units to transmit more easily upwards into the Clematis Sandstone.

Two additional scenarios were developed to predict the effects of underground mining and associated fracturing; however predictive uncertainty analysis was not undertaken on these. Modelling of the full SEIS mine plan (i.e. simulating both the open cut and underground mine workings) using the previous 2013 SEIS model fracturing assumptions (SEIS A), results in drawdowns that do not breach the DSC 0.2 m spring drawdown threshold. These are comparable to the 2013 SEIS model results. Modelling of the SEIS mine plan using updated fracturing and relief zone assumptions (SEIS B) based on outcomes from the RFCRP, predicts drawdown that does not breach the 0.2 m spring drawdown threshold, on the order of 5-10 cm.

Due to the current uncertainty associated with fracturing above, and relief zone around, the underground mining areas, it is recommended that the updated GMMP develops groundwater drawdown thresholds that are associated with the OC mining scenario only at this stage. Updated knowledge, where available, should be used in the next 5-year model review with accompanied future predictive uncertainty analysis. At this time, an optimised mine plan can also be developed for underground mining while also minimising impacts on the DSC. In addition, future GABSRP outcomes will likely develop more robust ecological water requirements (EWRs) for the springs. Future modelling should include updated EWRs and associated spring drawdown thresholds.

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The updated model simulates mine inflows far greater than the 2013 SEIS, largely due to the history-matching process adopting larger hydraulic conductivity and storage values for the Permian sediments. A basic analysis has shown that the modelled mine inflows are sensitive to the assumptions related to the modelled Permian sediment properties and, thus, further studies should concentrate on aquifer analysis related to Permian drawdown. The next 5-year model review will include a significant dataset related to Permian drawdown in response to ongoing mine dewatering and, thus, future history-matching can be better informed bythis dataset.

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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

The original model was developed by GHD in 2013 and is documented in detail as Appendix K1 of the original Supplementary Environmental Impact Statement (SEIS) titled 'Report for mine Hydrogeology Report", dated 13 November 2013. The modelling allowed for the simulation of a multilayered complex hydrogeological system, based on the site specific data collected at the time. The model was developed using MODFLOW-SURFACT, however given the datasets available, the model was only calibrated in steady state mode. This had raised previously review criticisms related to the ability of the model to inform valid model predictions. Subsequently, Commonwealth approval of the project was issued subject to a series of conditions, documented within Approval Carmichael Coal Mine and Rail Infrastructure Project, Queensland (EPBC 2010/5736). The EPBC Act Condition 23 required a re-run of the groundwater flow model, based on the independent expert review as per EPBC Act Condition 22.

Amongst other requirements, the main updates to the model and documentation included changes to the model edge boundary conditions, in particular related to the assumptions related to the General Head Boundary (GHB) arrangement, undertake an uncertainty analysis, and provide clear documentation related to discharge mechanisms and adopted recharge rates. GHD conducted the required modelling revisions and re-run. GHD considered that while the groundwater model is considered appropriate for the current stage of the project, the model will be updated in the future as the hydrogeological understanding of the Project and surrounding area continues to evolve. GHD compiled recommendations as a guide for future investigations and modelling studies. These include:

- 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
- re-calibrate the model, inclusive of transient calibration, with operational and regional monitoring data

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- incorporation of the weathered zone into the model
- review of recharge parameters, particularly in the GAB units.

On examining the impact predictions from the SEIS predictive groundwater model and re-run model scenarios (differing model boundaries) at important receptors, it was evident that the impacts are similar but higher in the original SEIS model. The current GMMP compilation (v11a, 2020) included a review of the previous models and a conservative approach was taken to use the original SEIS model (i.e. base the GMMP on the highest predicted impacts). The SEIS model predicts the highest magnitude of impacts and hence the results from the SEIS model have been used for all assessments and development of water quality triggers and water level thresholds included in the current GMMP.

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
- 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
- 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:

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- 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 base case realisation along with a suite of alternative realisations
- Section 5 – Base case prediction and predictive uncertainty analysis
- Section 6 - Approach to addressing past model review criticism
- Section 7 – Summary and recommendations.

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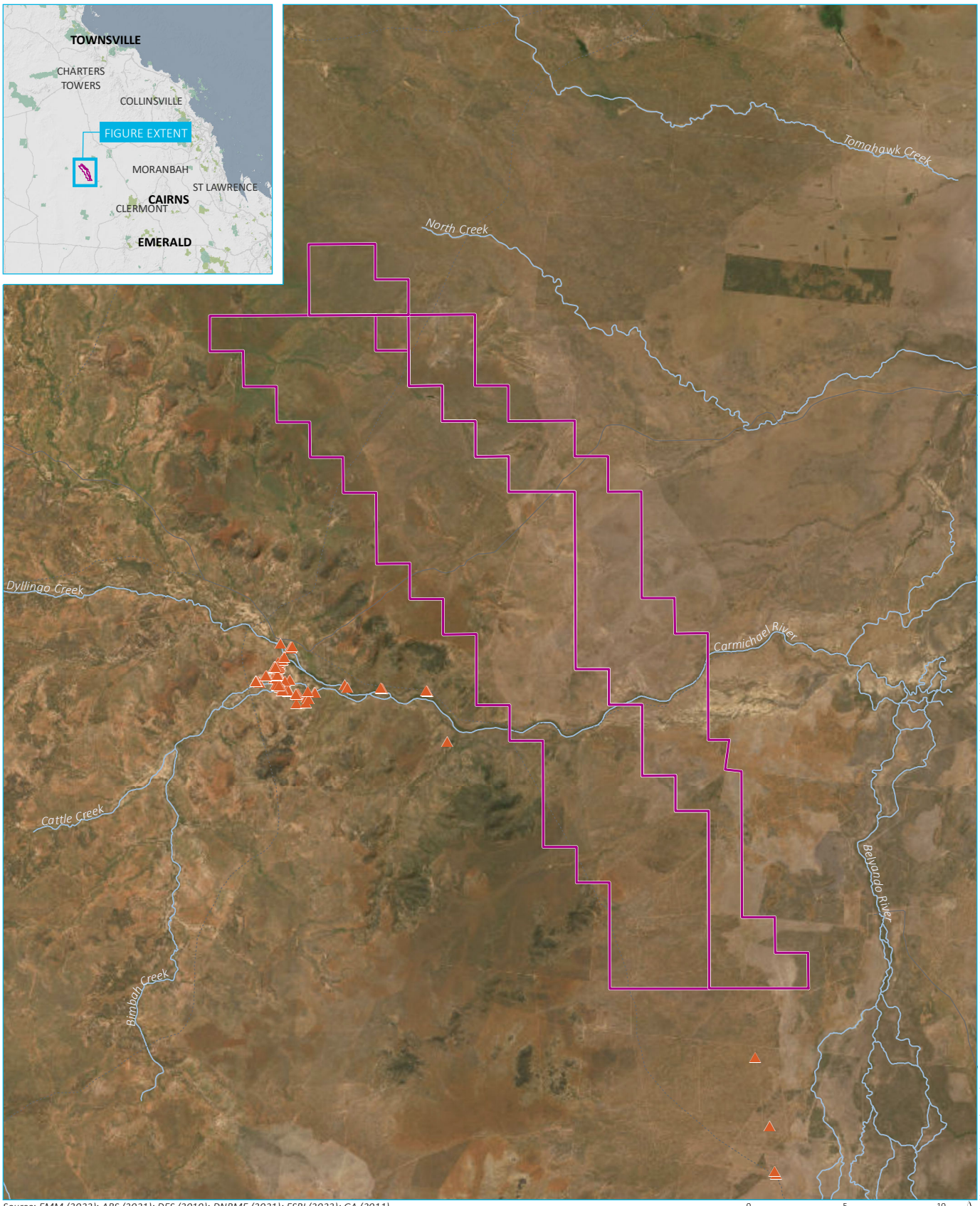

Source: EMM (2022); ABS (2021); DES (2019); DNRME (2021); ESRI (2022); GA (2011)

0 5 10 km

GDA 1994 MGA Zone 55

N

Carmichael coal mine location map

KEY

- Mining lease
- Spring
- Major watercourse
- Minor road
- Vehicular track

INSET KEY

- Major road
- National park/nature reserve
- State forest

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Carmichael Coal Mine
GMMP Review
Figure 1.1

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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 backets within this report:

a) a review of the hydrogeological conceptualisation used in the previous model (EMM 2022a, Section 2)

b) an update of the predicted impacts (Section 5)

c) a revised water balance model (Section 4 and 5)

d) a review of assumptions used in the previous model (Section 3)

e) predictions of changes in groundwater levels for a range of scenarios (Section 5)

f) any changes made since the previous model review, including data changes (Section 3)

g) a justification for the refined model and the outputs of the refined model (Section 3)

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 4)

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 G).

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 6.

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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.

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

Feature of conceptual model	Summary of key knowledge
Hydrogeological framework	The main stratigraphic units of relevance to the CCM include, from top to bottom: • 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. 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.
Faults and structures	• 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	• 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. 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.

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

Feature of conceptual model	Summary of key knowledge
Local groundwater flow	Local groundwater flow characteristics differ based on hydrostratigraphic unit (HSU), with the main points summarised as follows: • 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	The recharge and discharge mechanisms of each stratigraphic unit can be summarised as follows: <u>Recharge</u> • 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 though vertical leakage from other units. • Regional groundwater flows towards the local aquifers from the west. <u>Discharge</u> • 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.

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

Feature of conceptual model	Summary of key knowledge
Groundwater stresses	• 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	Prior SEIS modelling and aquifer testing work has determined the following horizontal hydraulic conductivity value ranges for each of the HSUs: • Alluvium: $3x10^{-2}$ – 11 m/d • Tertiary sediments: $2x10^{-4}$ – $1.7x10^{-1}$ m/d • Moolayember Formation: $5x10^{-2}$ m/d • Clematis Sandstone: $1x10^{-2}$ – 15 m/d • Dunda Beds: $2x10^{-3}$ – 3 m/d • Rewan Formation: $1x10^{-4}$ – 0.29 m/d • Bandanna Formation: $1x10^{-4}$ – 35 m/d • Colinlea Sandstone: $1x10^{-4}$ – $2x10^{-1}$ m/d • Joe Joe Group: $2x10^{-4}$ – $4.1x10^{-1}$ m/d • As part of the recent RFCRP, the median horizontal hydraulic conductivity of the Rewan Formation was determined to be $2.4x10^{-4}$ m/d with specific storage values ranging between 3.7×10^{-7} to 6.6×10^{-6} m^{-1}
Groundwater-surface water interactions	• 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.

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

Feature of conceptual model	Summary of key knowledge
Groundwater dependent ecosystems	• 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	• 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.

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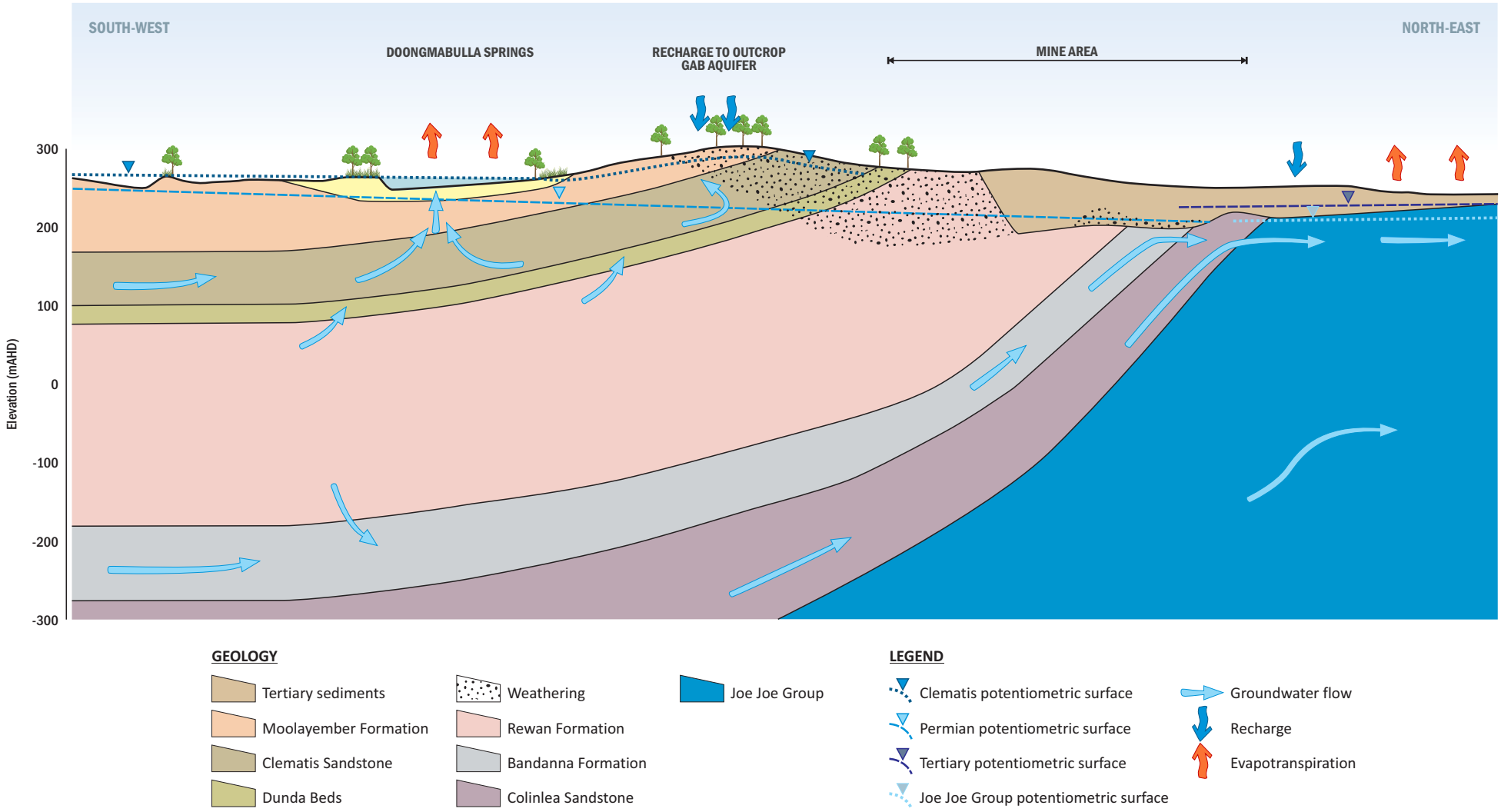


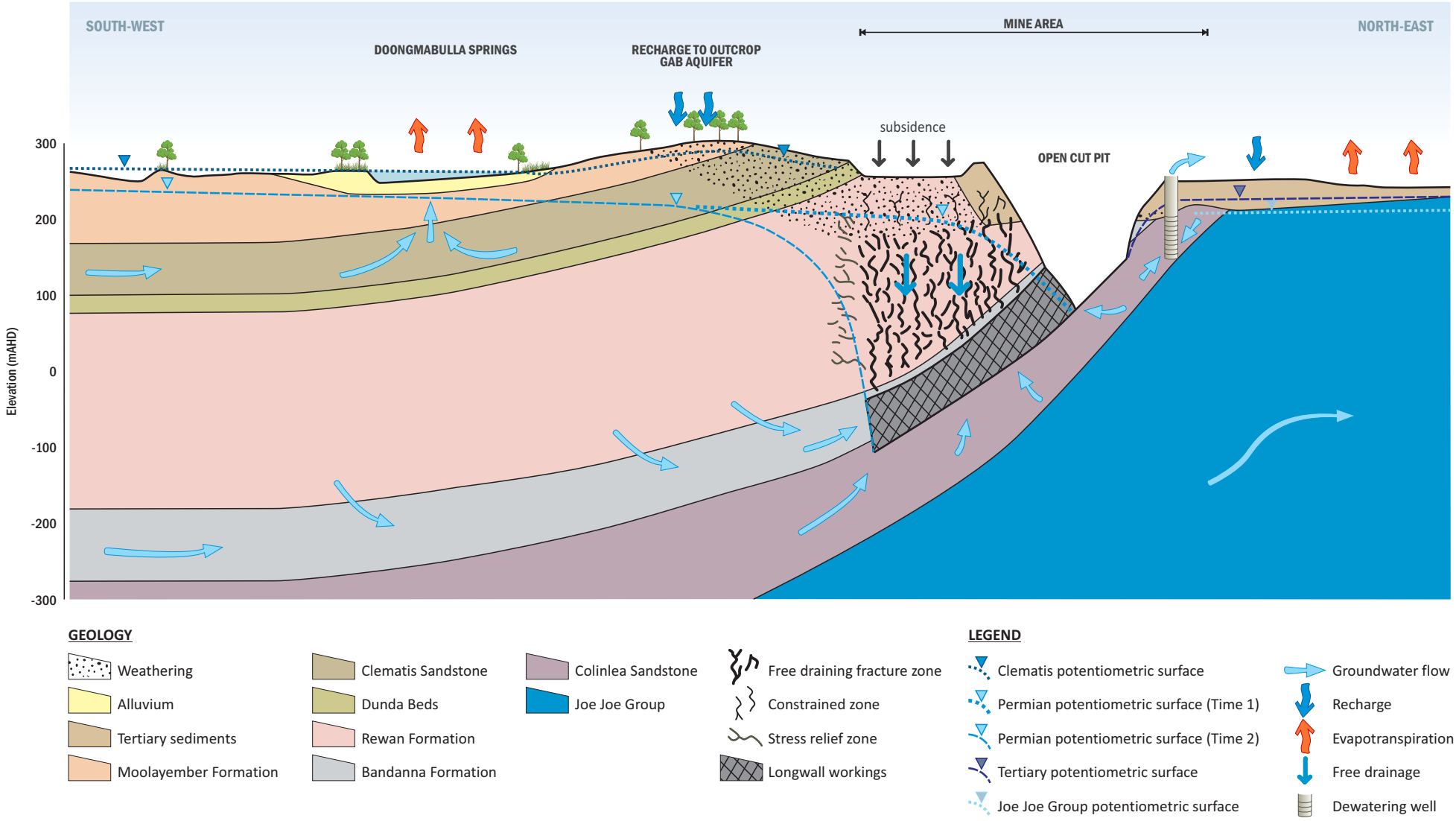
Pre-mining hydrogeological conceptual model

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

Bravus Mining & Resources

Figure 2.1

EMM creating opportunities



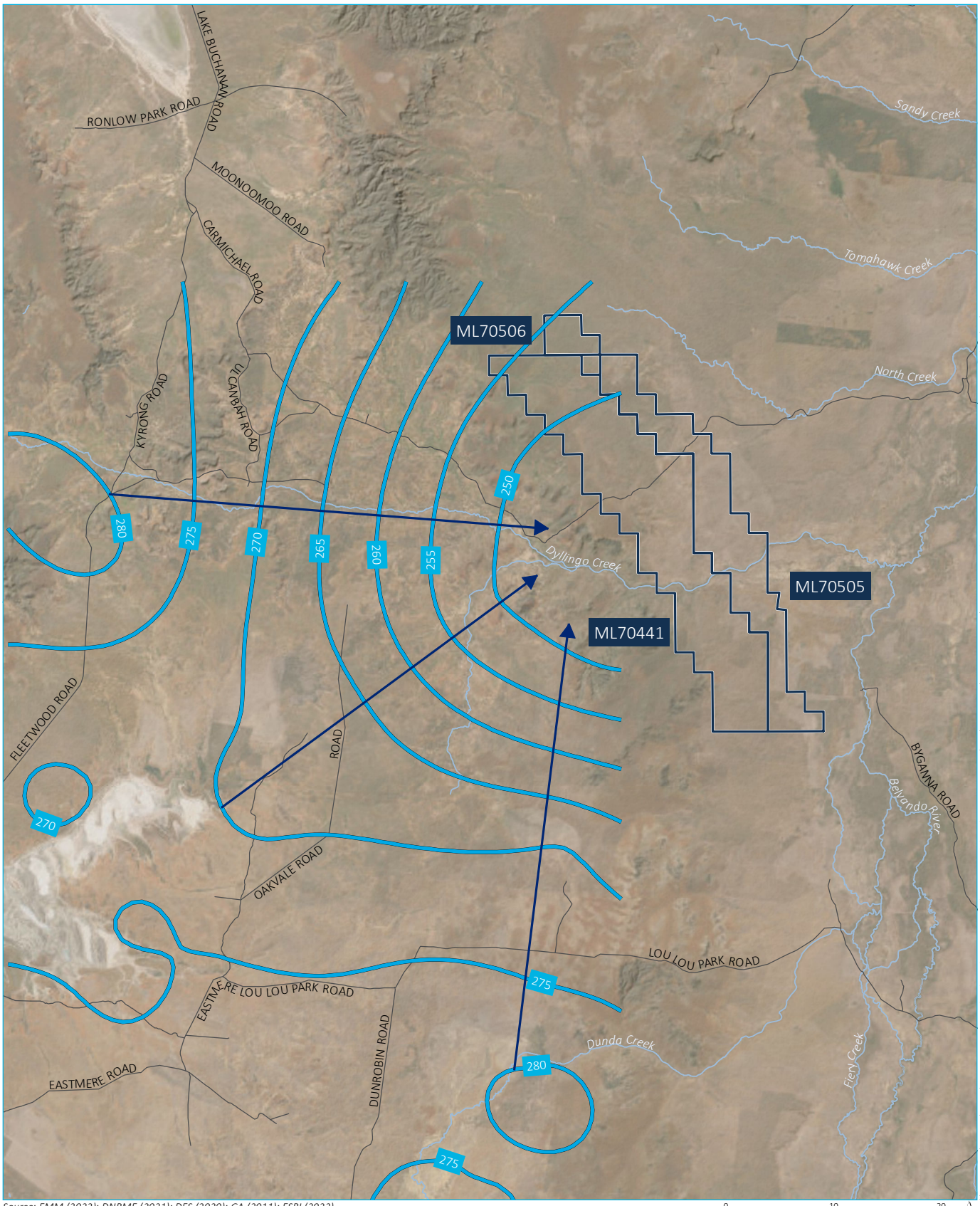
Mining hydrogeological conceptual model

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

Bravus Mining & Resources

Figure 2.2

EMM creating opportunities



Source: EMM (2022); DNRME (2021); DES (2020); GA (2011); ESRI (2022)

0 10 20 km

GDA 1994 MGA Zone 55

N

KEY

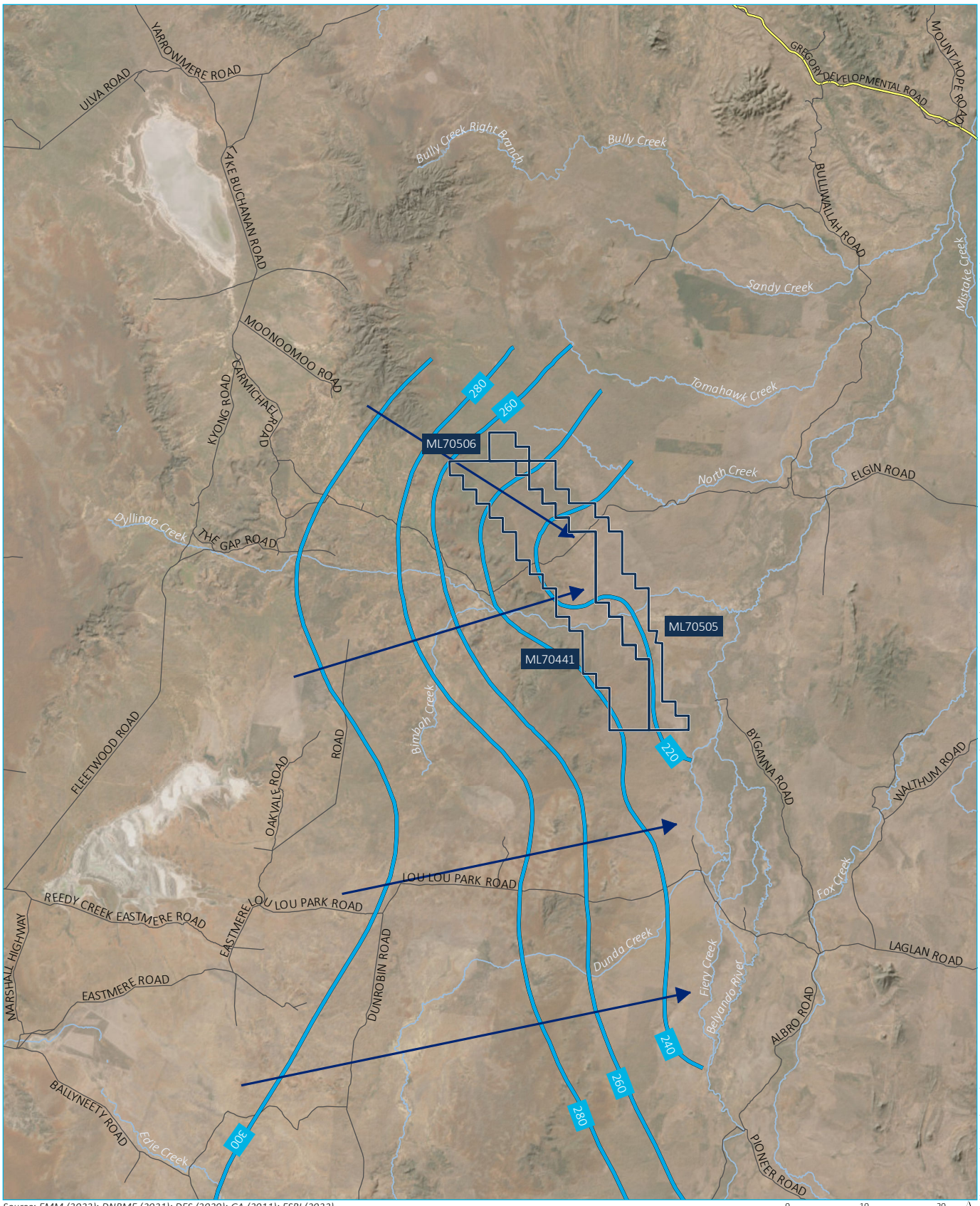
- Mining lease
- Interpreted groundwater flow line
- Groundwater elevation (mAHD)
- Minor road
- Named watercourse

Conceptual regional groundwater contours in Clematis Sandstone

Carmichael Coal Mine
GMMP Review
Figure 2.3

EMM creating opportunities

\\emmsvr1\emm3\2021\E210818 - Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G004_GroundwaterContourClematis_20230111_01.mxd 12/01/2023



Source: EMM (2022); DNRME (2021); DES (2020); GA (2011); ESRI (2022)

0 10 20 km

GDA 1994 MGA Zone 55

N

\\emmsvr1\emm3\2021\E210818 - Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G005_GroundwaterContourPermianInterburden_20230111_01.mxd 12/01/2023

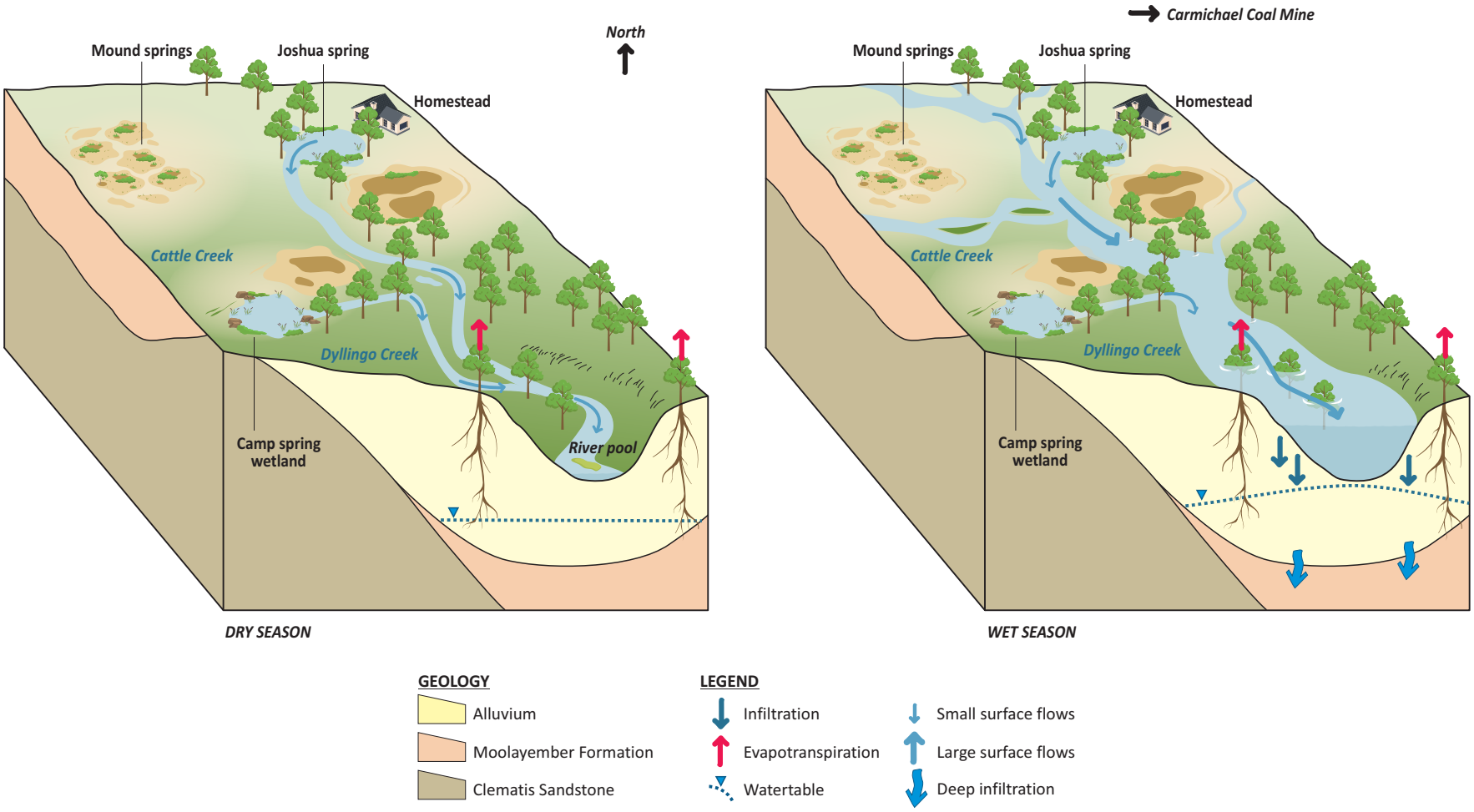
KEY

- Mining lease
- Interpreted groundwater flow line
- Groundwater elevation (mAHD)
- Major road
- Minor road
- Named watercourse

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

Carmichael Coal Mine
GMMP Review
Figure 2.4

EMM creating opportunities



NOT TO SCALE

Note: Conceptual representation only.

Surface water/groundwater interaction conceptual model

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

Bravus Mining & Resources

Figure 2.5

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 regarding predictive uncertainty analysis, a new model has been developed rather than 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:

- To simulate regional-scale groundwater impacts a simplified modelling approach was needed.
- 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
- include model boundary conditions such that regional flow directions can be simulated.

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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
- 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.

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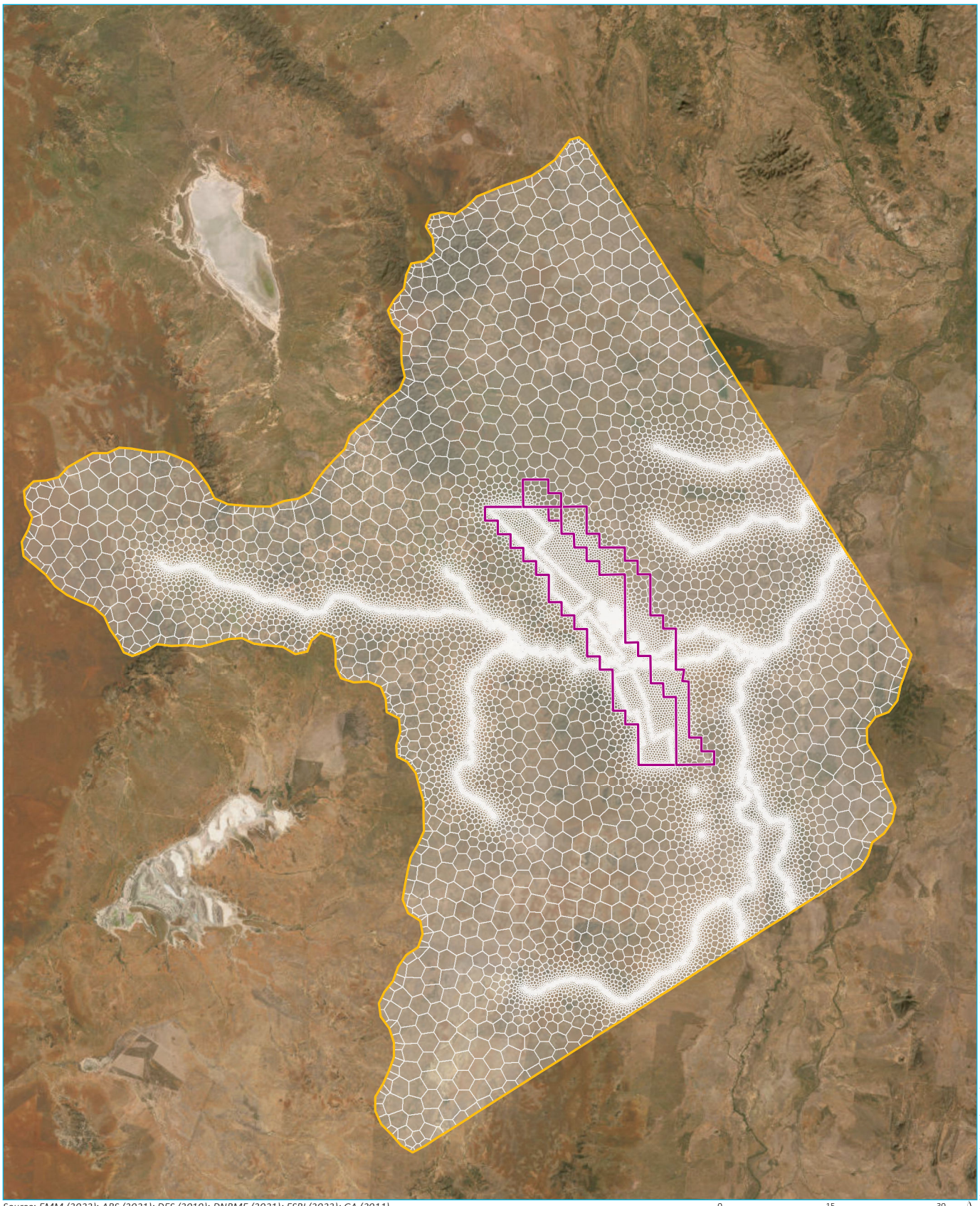


Source: EMM (2022); ABS (2021); DES (2019); DNRME (2021); ESRI (2022); GA (2011)

0 15 30 km

GDA 1994 MGA Zone 55

N

KEY

- Mining lease
- Model domain
- Model domain mesh

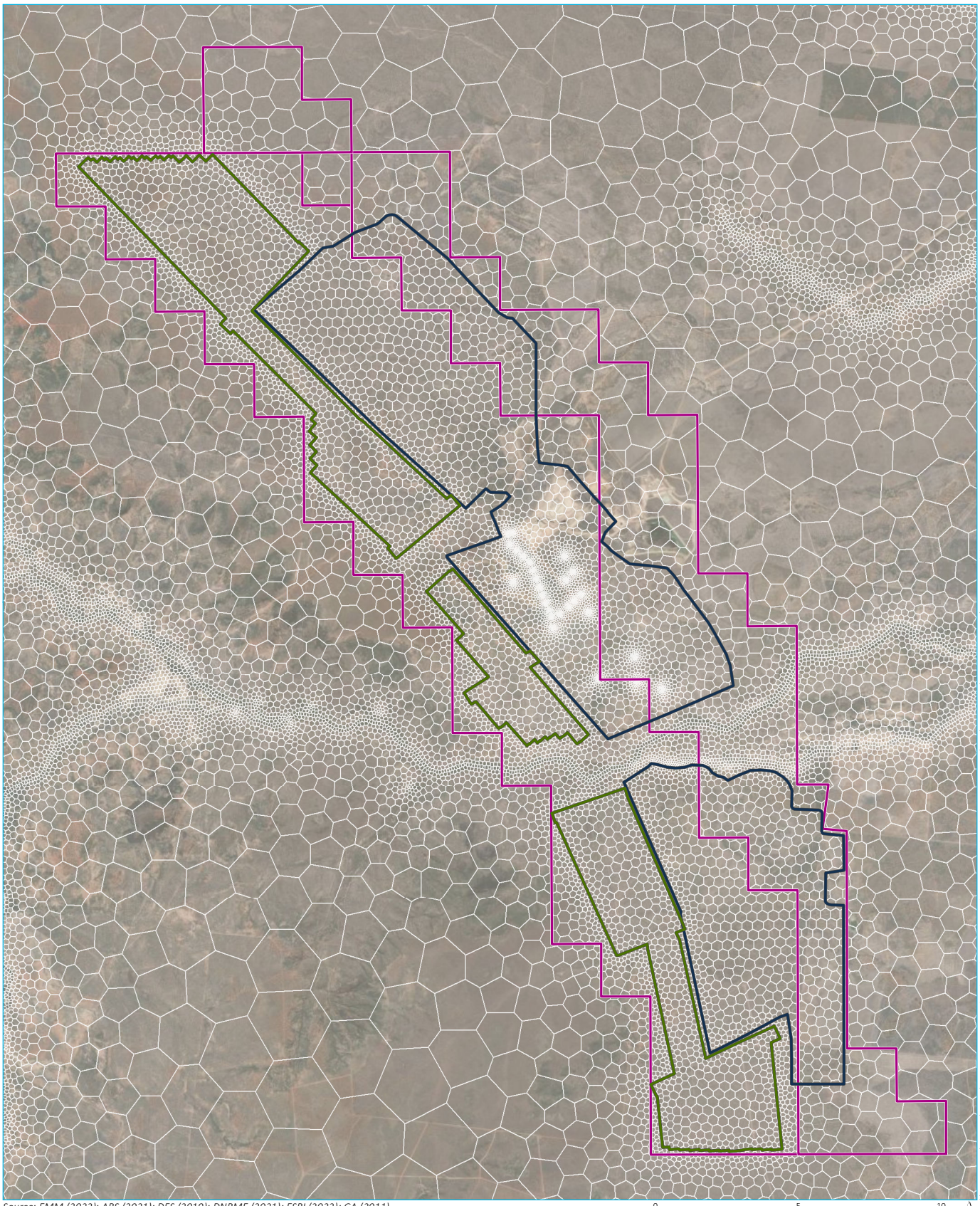
Model domain and Voronoi mesh

DRAFT

Carmichael Coal Mine
GMMP Review
Figure 1.1

EMM
creating opportunities

\\emmsvr1\emm3\2021\E210818 - Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G006_ModelDomainMesh_20230111.mxd 12/01/2023



Source: EMM (2022); ABS (2021); DES (2019); DNRME (2021); ESRI (2022); GA (2011)

0 5 10 km

GDA 1994 MGA Zone 55

N

KEY

- Mining lease
- Underground mine plan
- Open cut mine plan
- Model domain mesh

Voronoi mesh in mine area

DRAFT

Carmichael Coal Mine
GMMP Review
Figure 3.2

EMM creating opportunities

\\emmsvr1\emm3\2021\E210818 - Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G007_ModelDomainMineArea_20230111.mxd 12/01/2023

3.3.2 Layers

The HSUs in the study area have been described in EMM (2022a) and summarised in Section 2. 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)
- 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.

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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.

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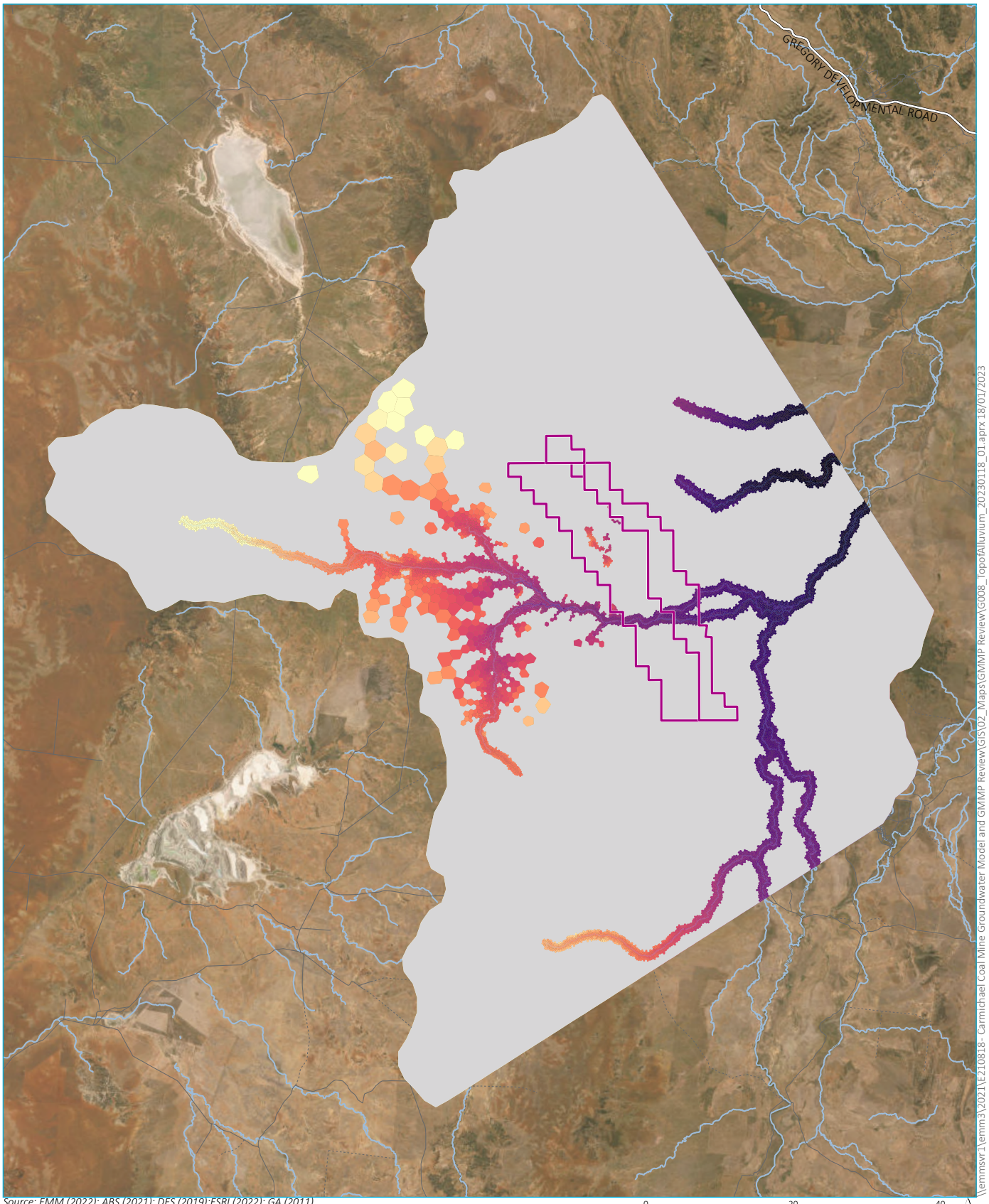

Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Inactive area
- Major road
- Minor road
- Vehicular track

Elevation (mAHD)

190

310

Top of alluvium (layer 1)

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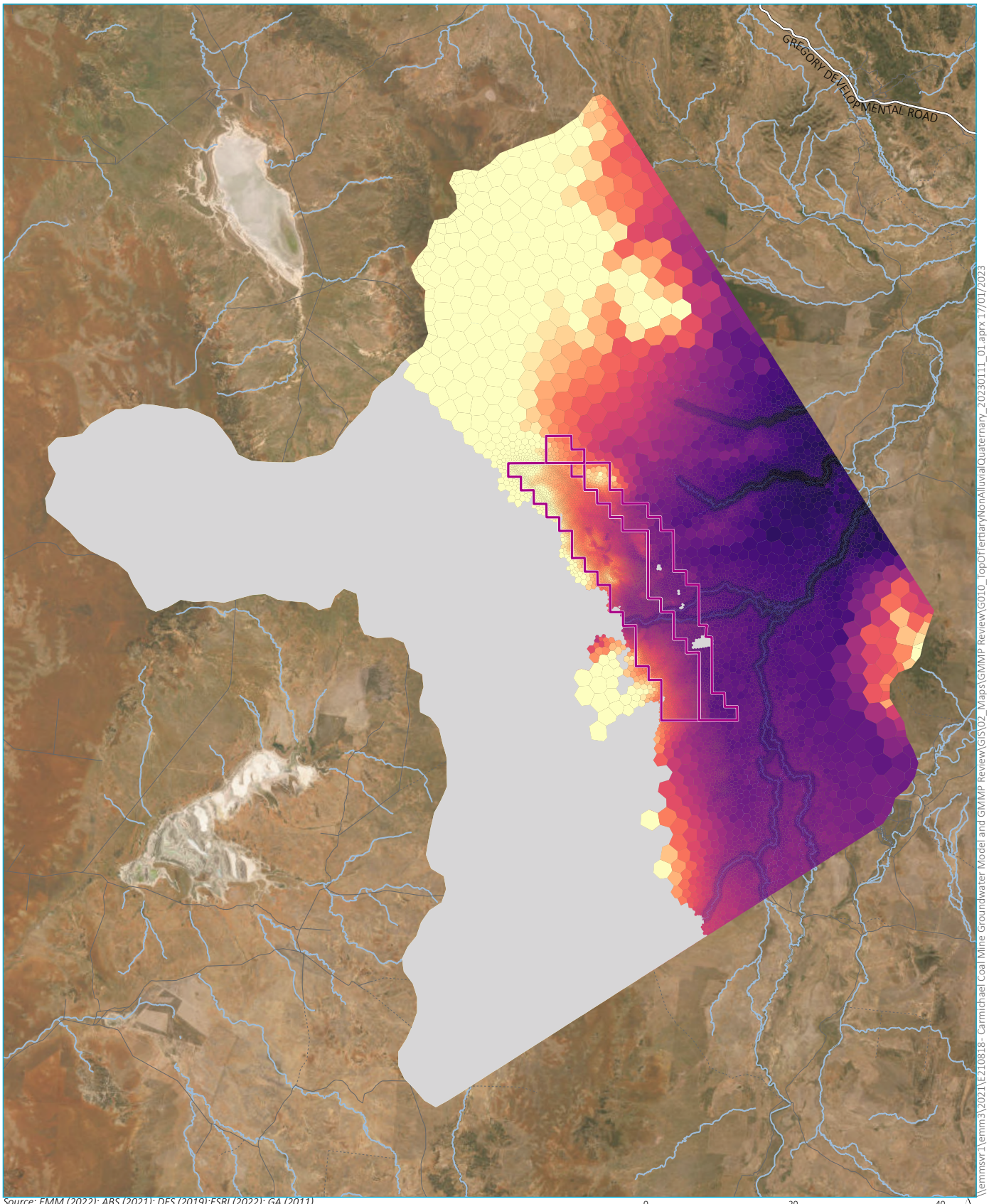
Carmichael Coal Mine
GMMP Review
Figure 3.3

EMM
creating opportunities

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G008_TopofAlluvium_20230118_01.aprx 18/01/2023



\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G010_TopOfTertiaryNonAlluvialQuaternary_20230111_01.aprx 17/01/2023

Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Inactive area
- Major road
- Minor road
- Vehicular track

Elevation (mAHD)

180

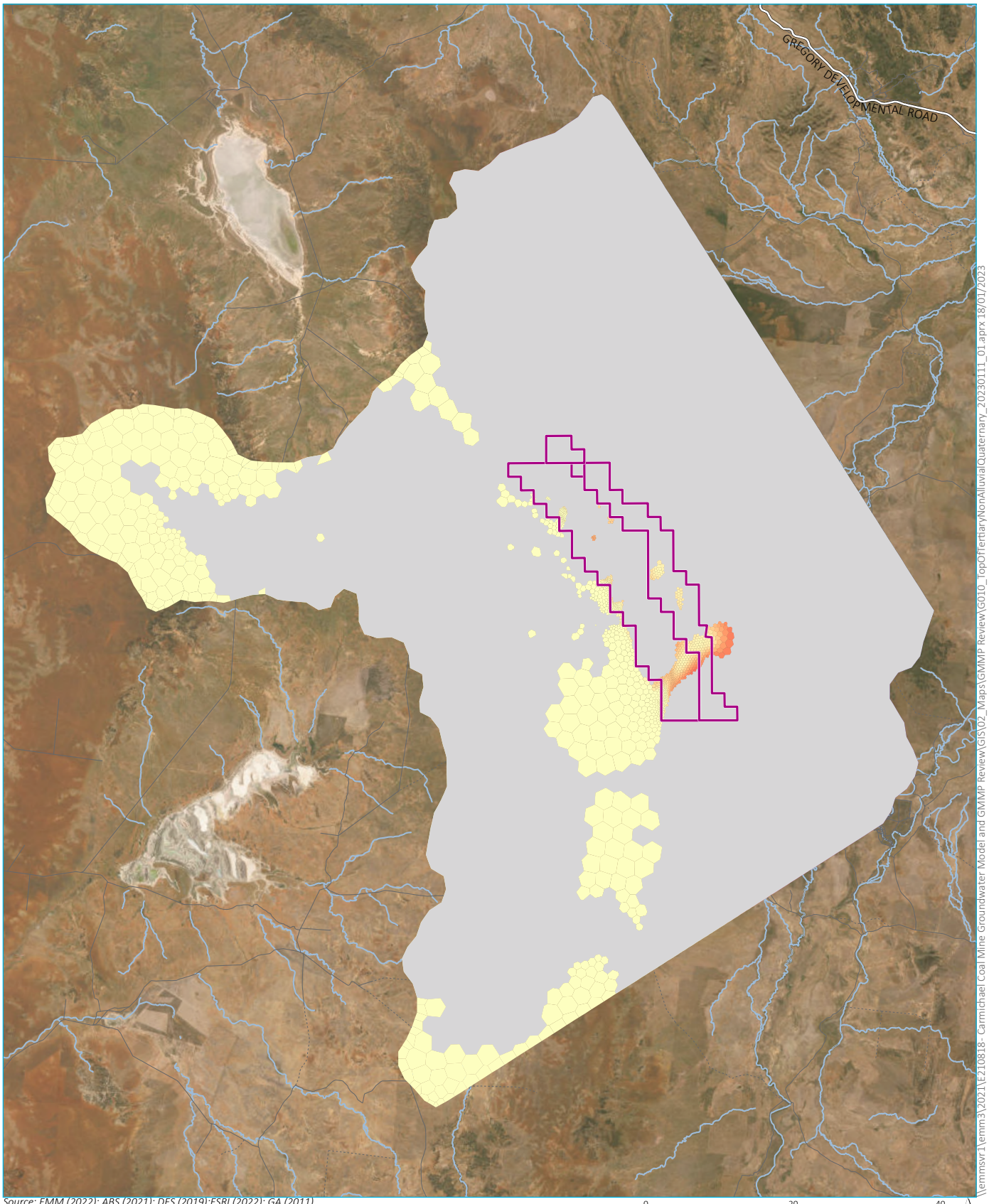
310

Top of weathering zone (layer 2)

DRAFT

Carmichael Coal Mine
GMMP Review
Figure 3.4

EMM
creating opportunities



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Inactive area
- Major road
- Minor road
- Vehicular track

Elevation (mAHD)

-83

230

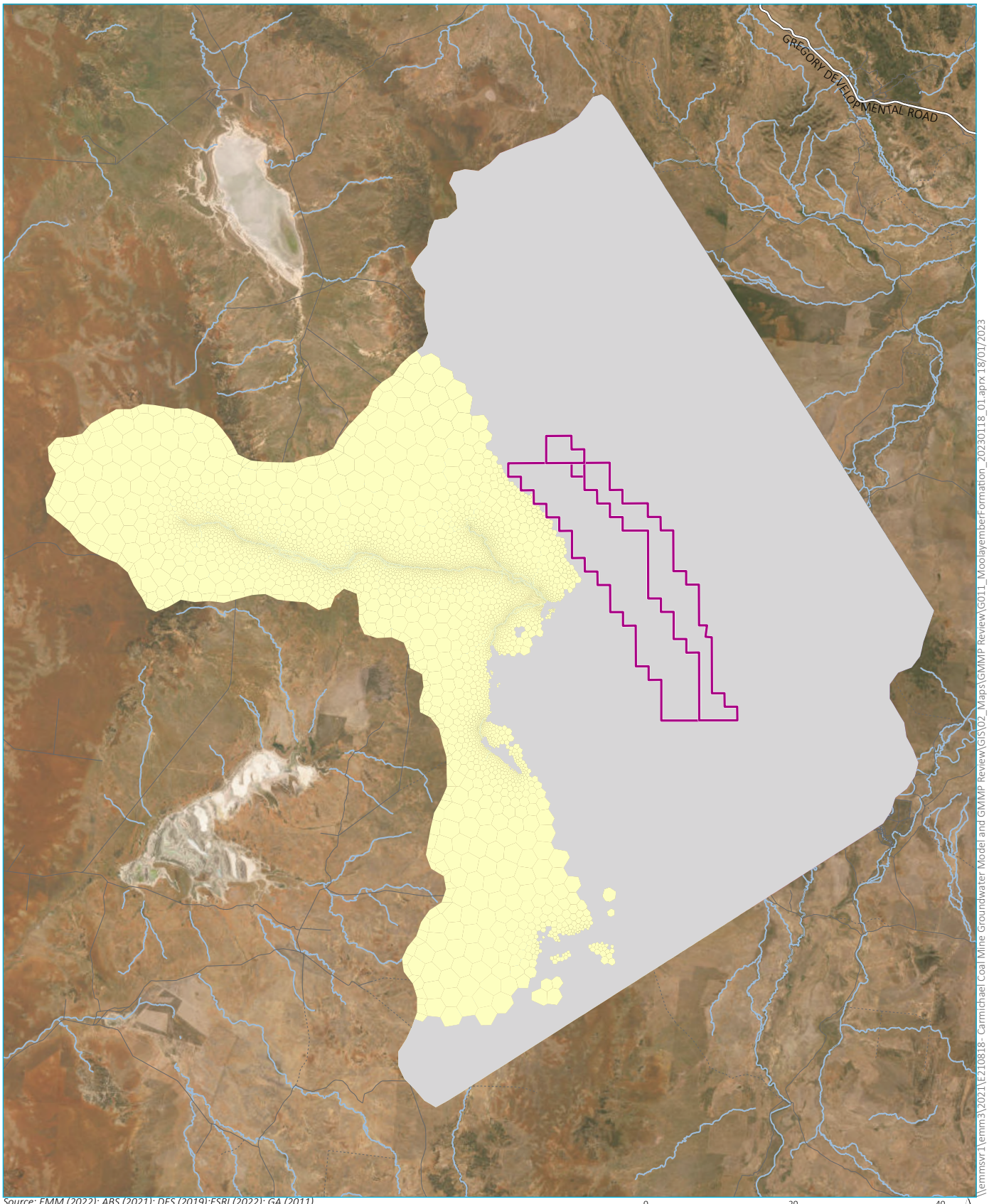
DRAFT

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

Carmichael Coal Mine
GMMP Review
Figure 3.5

EMM
creating opportunities

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G010_TopOfTertiaryNonAlluvialQuaternary_20230111_01.aprx 18/01/2023



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Inactive area
- Major road
- Minor road
- Vehicular track

Elevation (mAHD)

-83

220

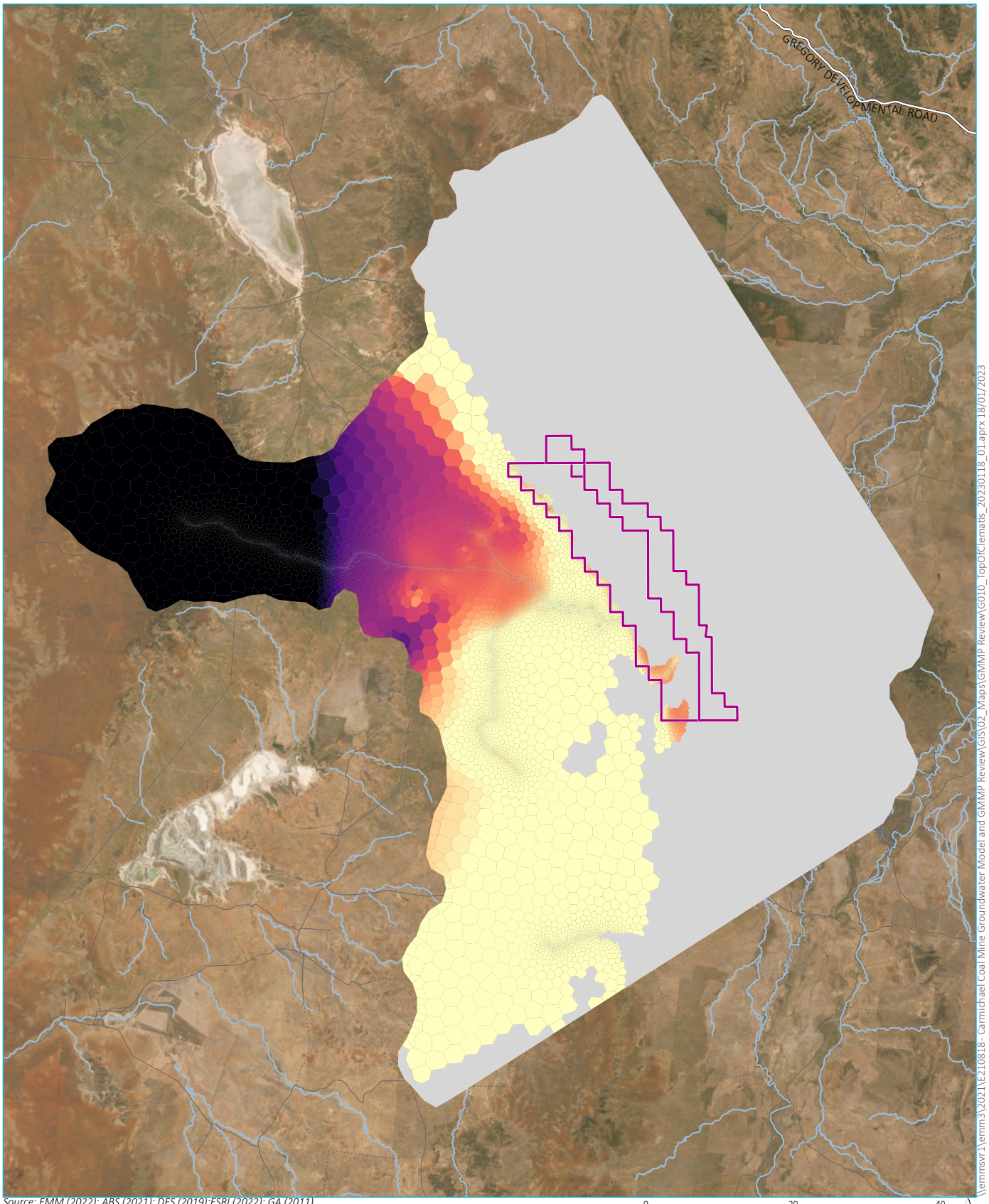
Top of Moolayember Formation (layer 4)

DRAFT

Carmichael Coal Mine
GMMP Review
Figure 3.6

EMM
creating opportunities

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G011_MoolayemberFormation_20230118_01.aprx 18/01/2023



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Inactive area
- Major road
- Minor road
- Vehicular track

Elevation (mAHD)

-83

220

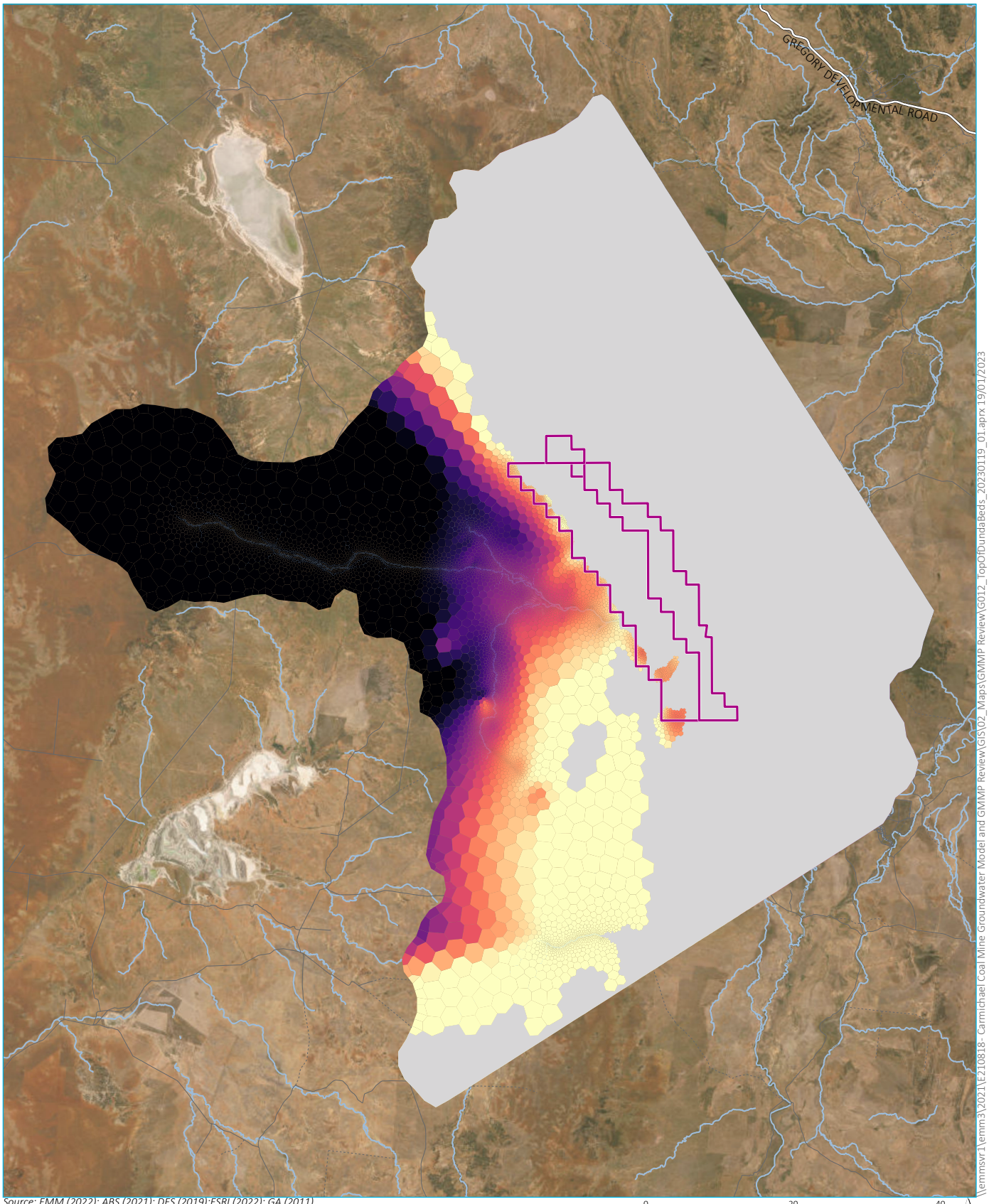
DRAFT

Top of Clematis Sandstone / Warang Sandstone (layer 5)

Carmichael Coal Mine
GMMP Review
Figure 3.7

EMM creating opportunities

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G010_TopOfClematis_20230118_01.aprx 18/01/2023



\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G012_TopOfDundaBeds_20230119_01.aprx 19/01/2023

Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Inactive area
- Major road
- Minor road
- Vehicular track

Elevation (mAHD)

-83

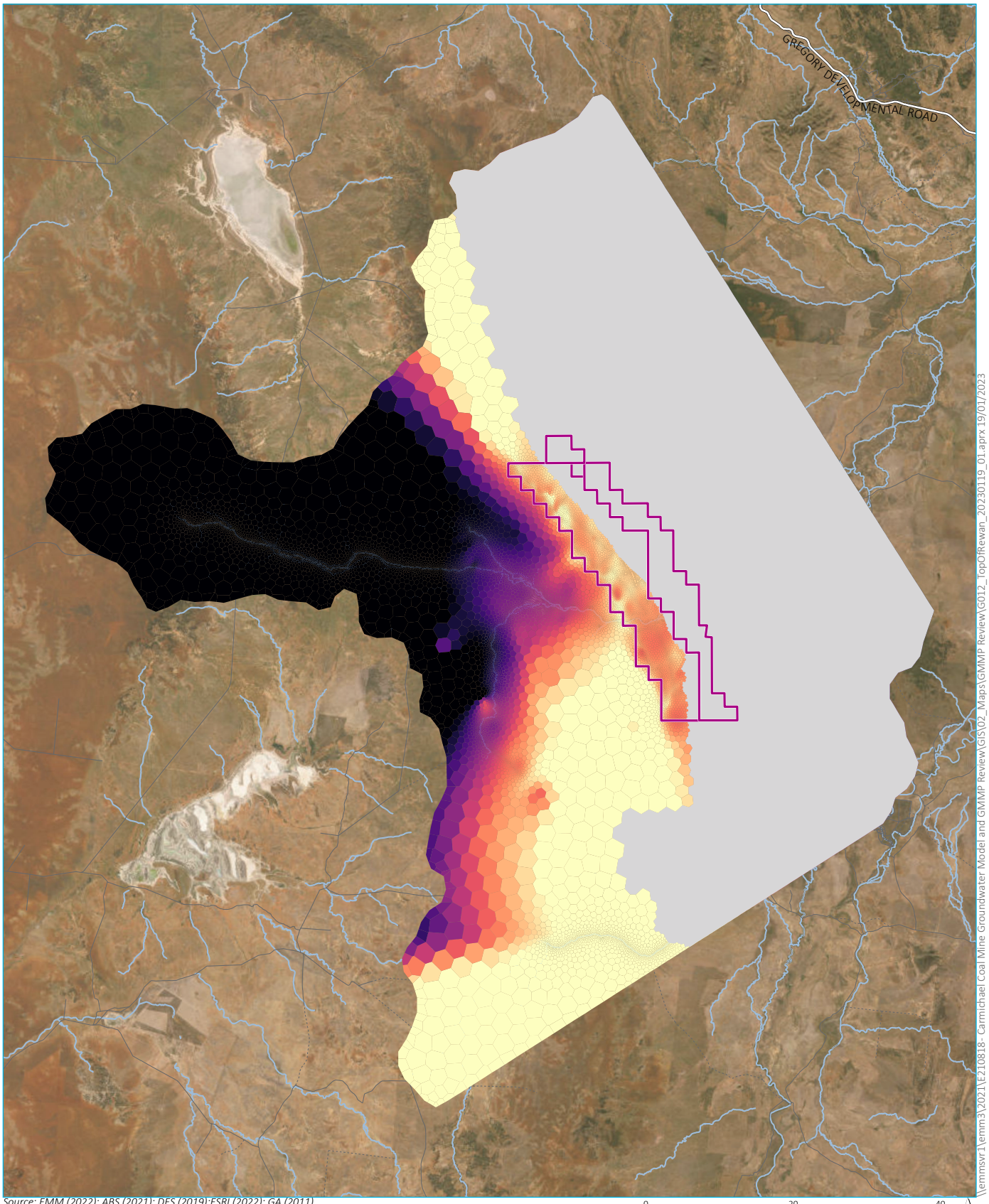
220

DRAFT

Top of Dunda Beds (layer 6)

Carmichael Coal Mine
GMMP Review
Figure 3.8

EMM
creating opportunities



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Inactive area
- Major road
- Minor road
- Vehicular track

Elevation (mAHD)

-83

220

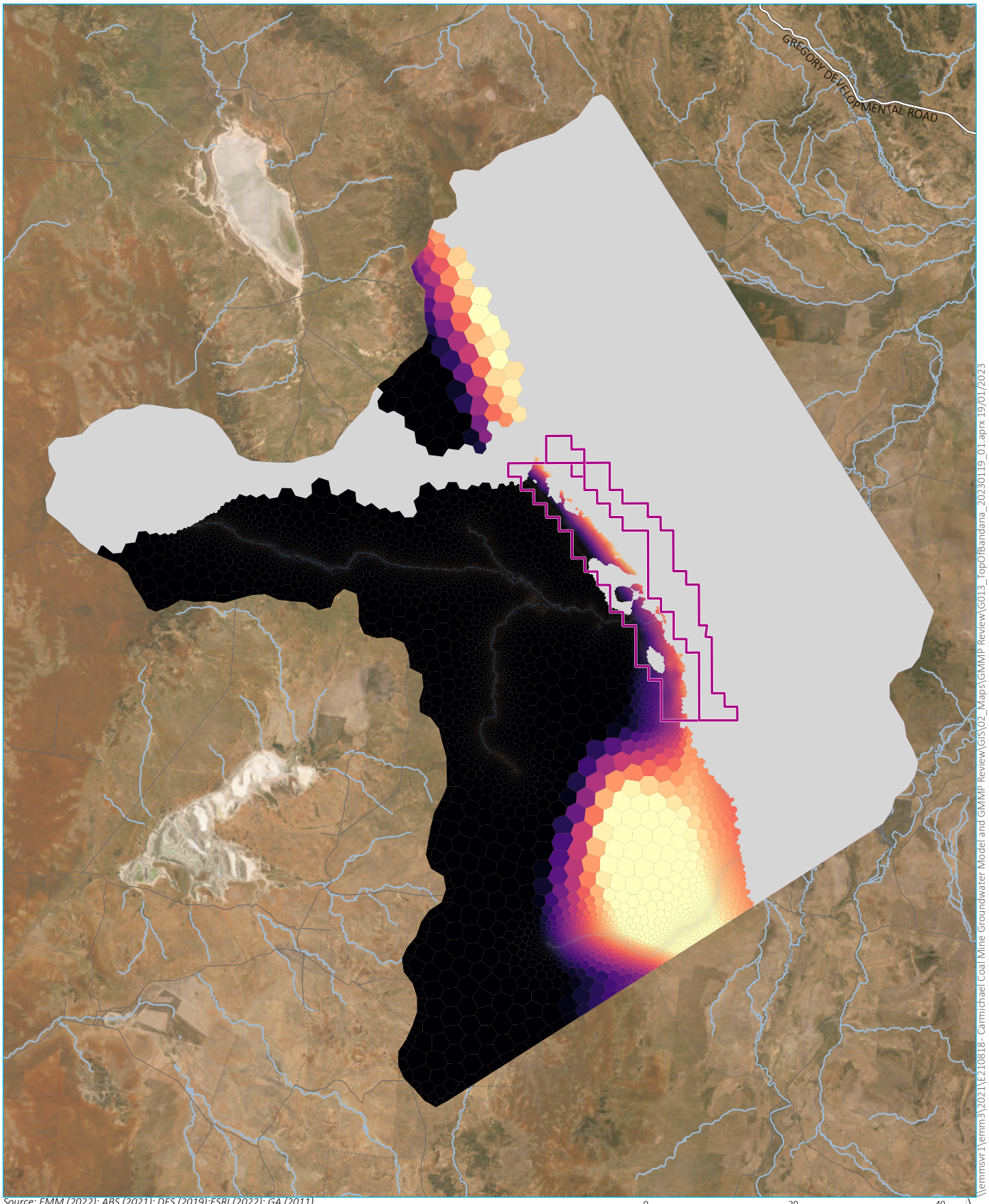
Top of Rewan Formation (layer 7-8)

DRAFT

Carmichael Coal Mine
GMMP Review
Figure 3.9

EMM
creating opportunities

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G012_TopOfRewan_20230119_01.aprx 19/01/2023



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Inactive area
- Major road
- Minor road
- Vehicular track

Elevation (mAHD)

-93

220

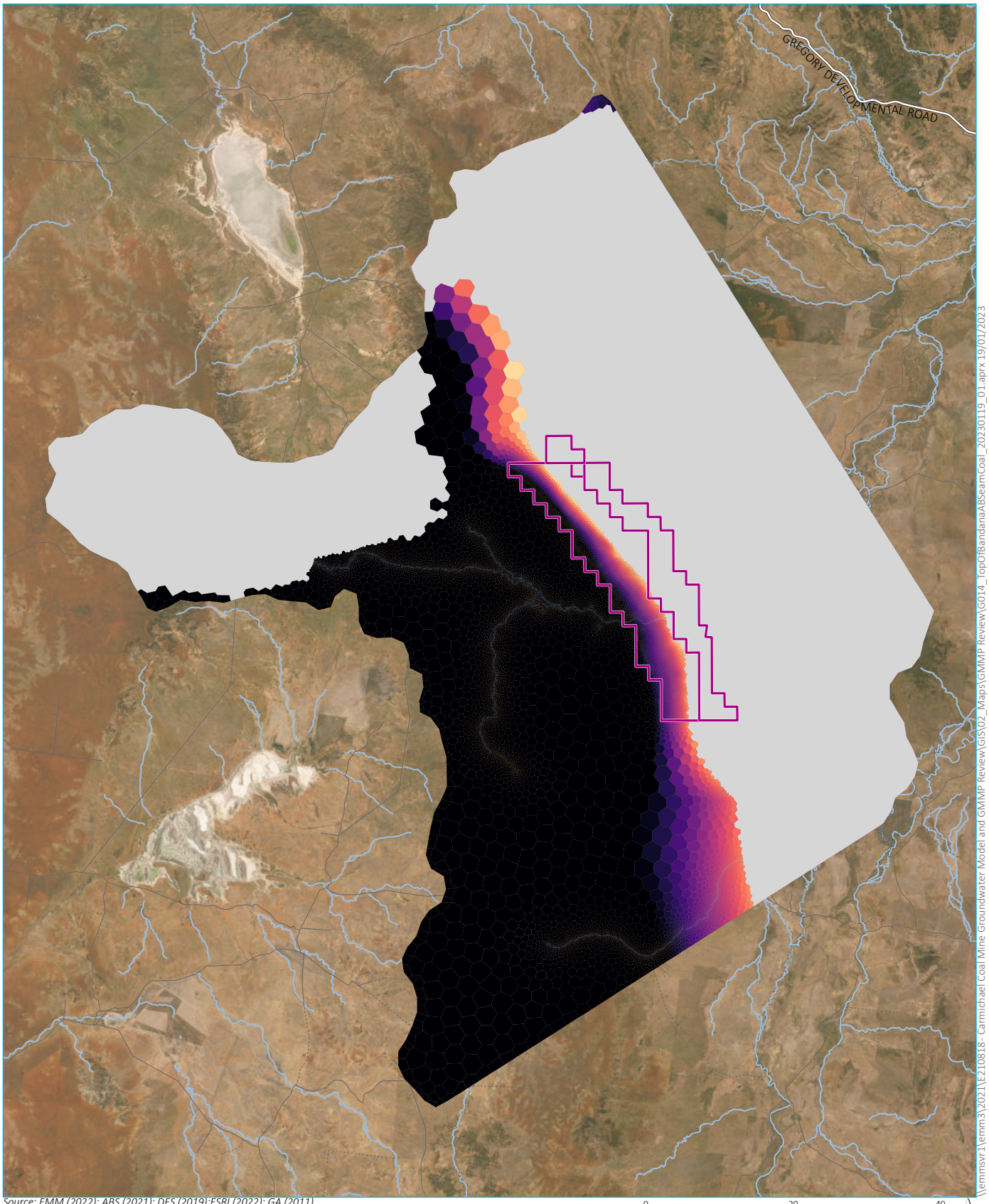
Top of Bandanna Formation (layer 9)

DRAFT

Carmichael Coal Mine
GMMP Review
Figure 3.10

EMM
creating opportunities

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G013_TopOfBandana_20230119_01.aprx 19/01/2023



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Inactive area
- Major road
- Minor road
- Vehicular track

Elevation (mAHD)

-97

220

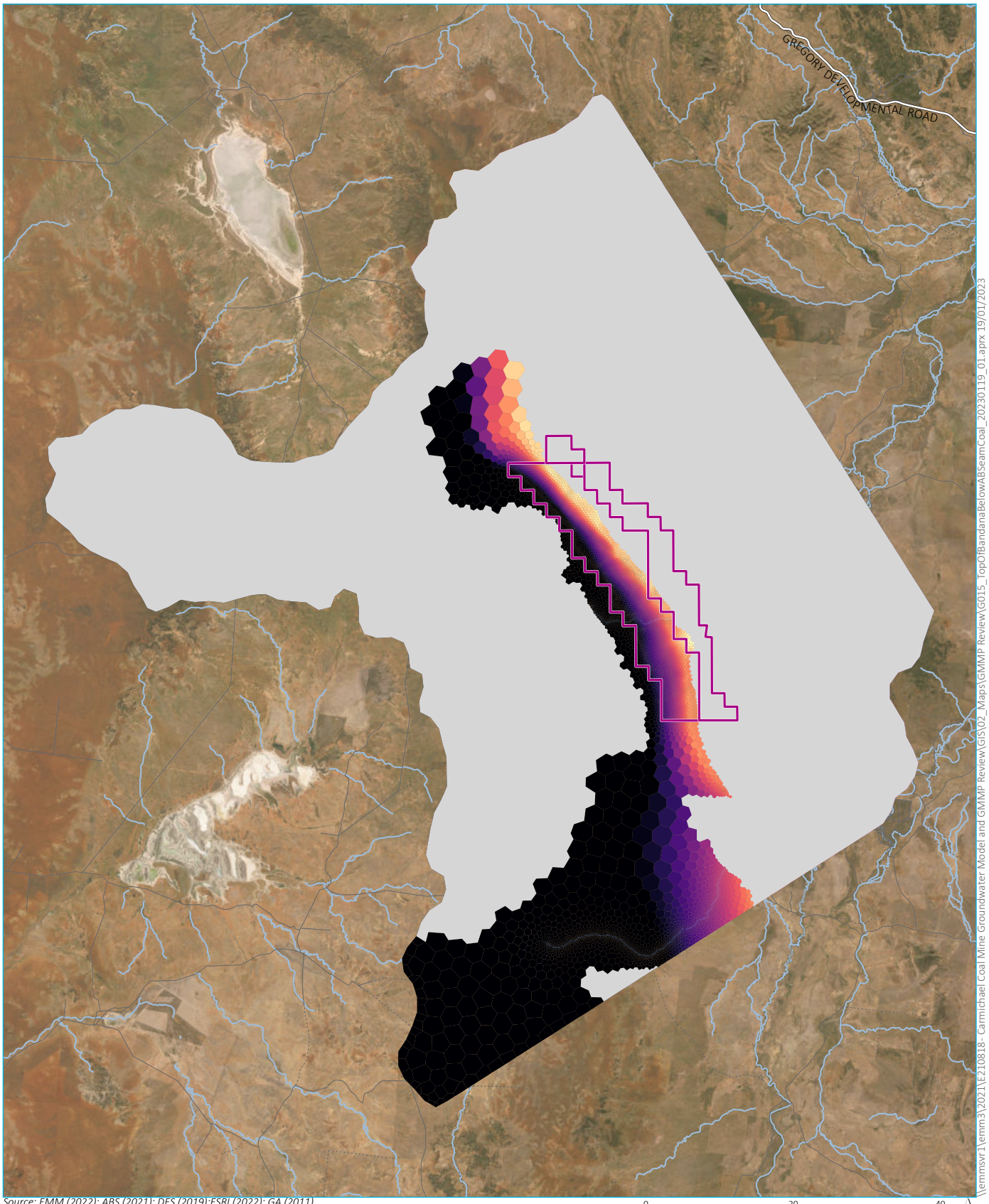
DRAFT

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

Carmichael Coal Mine
GMMP Review
Figure 3.11

EMM
creating opportunities

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G014_TopOfBandannaABSeamCoal_20230119_01.aprx 19/01/2023



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Inactive area
- Major road
- Minor road
- Vehicular track

Elevation (mAHD)

-110

220

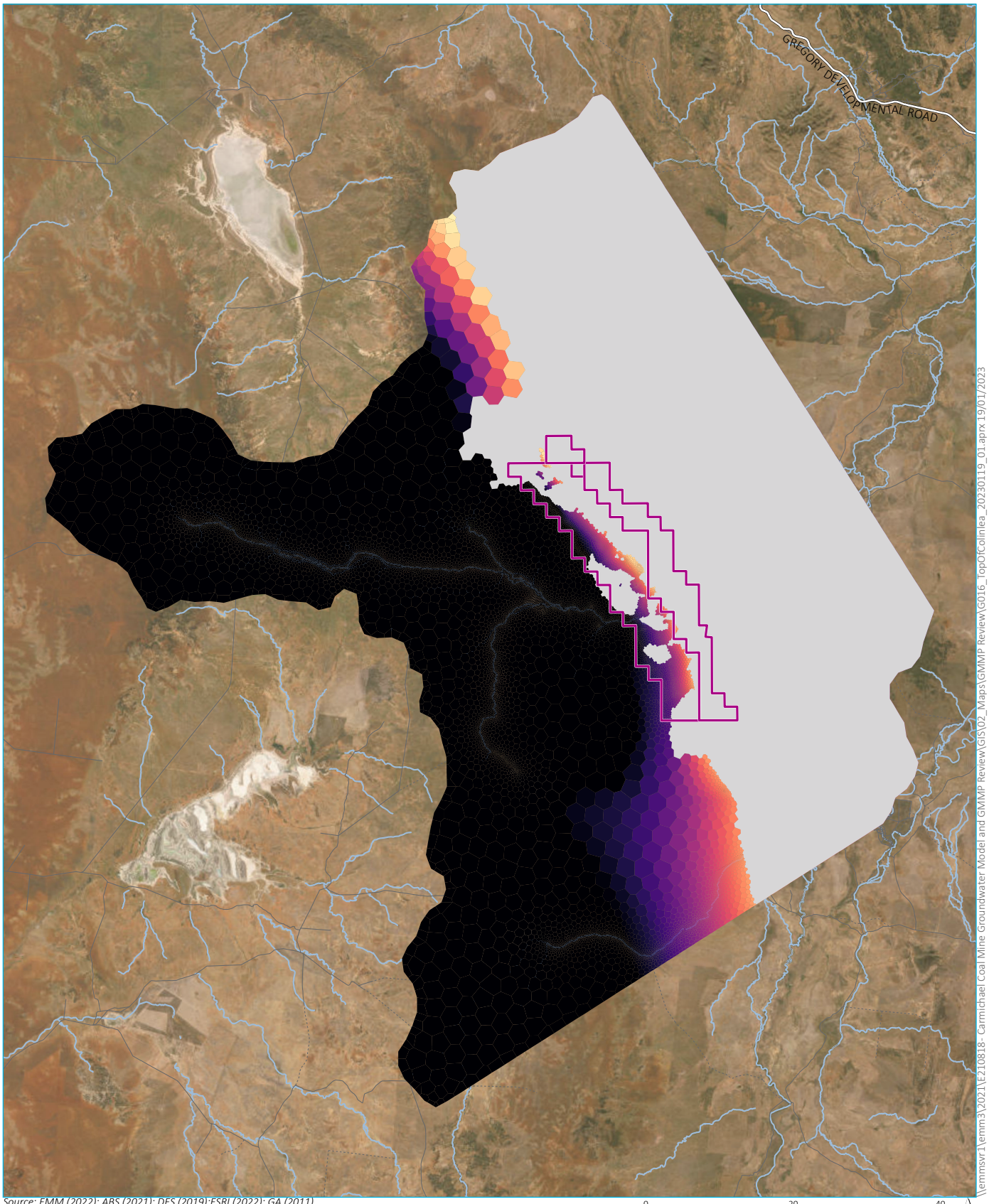
DRAFT

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

Carmichael Coal Mine
GMMP Review
Figure 3.12

EMM
creating opportunities

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G015_TopOfBandannaBelowABSeamCoal_20230119_01.aprx 19/01/2023



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Inactive area
- Major road
- Minor road
- Vehicular track

Elevation (mAHD)

-180

220

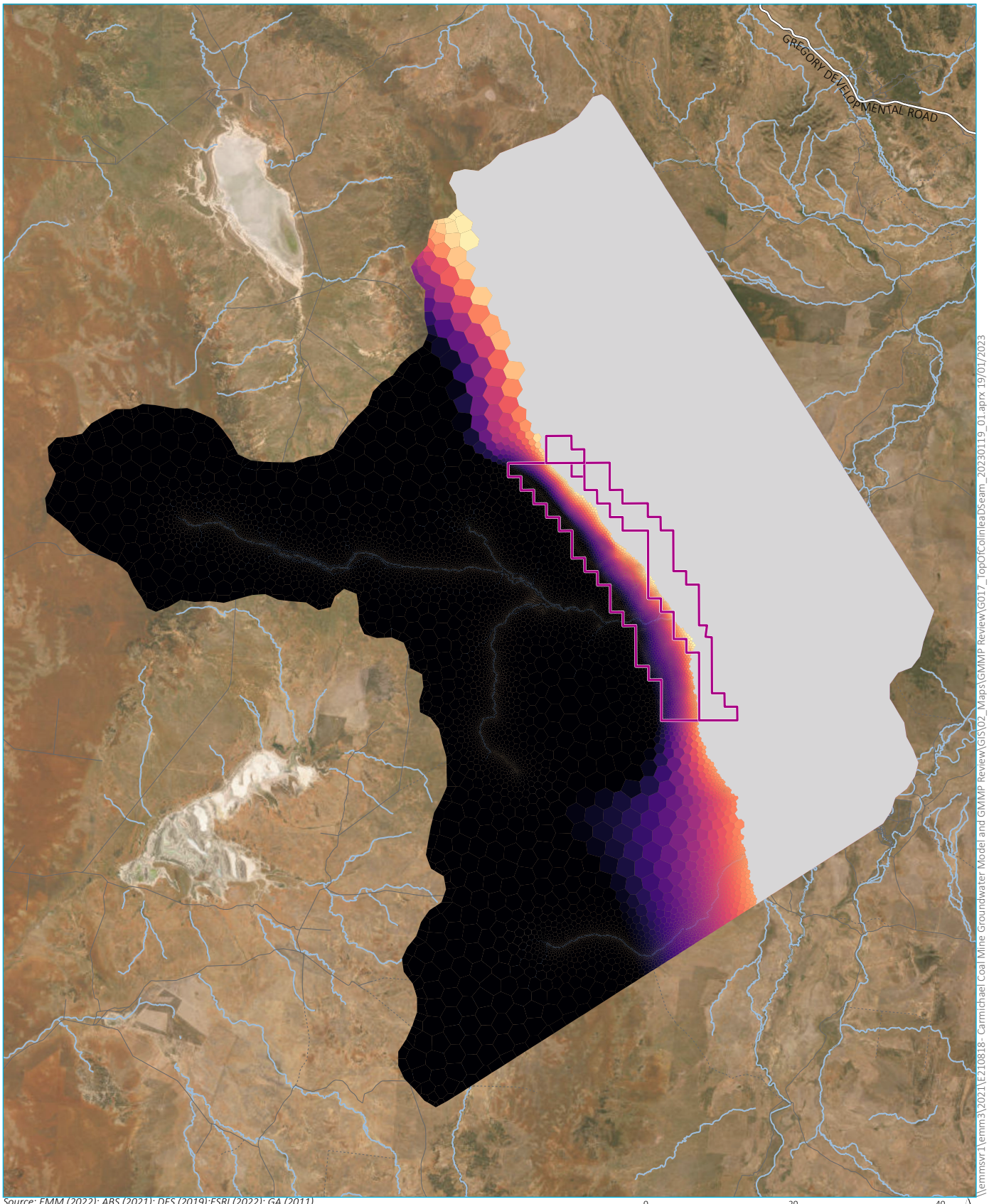
Top of Colinlea Sandstone (layer 12)

DRAFT

Carmichael Coal Mine
GMMP Review
Figure 3.13

EMM
creating opportunities

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G016_TopOfColinlea_20230119_01.aprx 19/01/2023



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Inactive area
- Major road
- Minor road
- Vehicular track

Elevation (mAHD)

-180

220

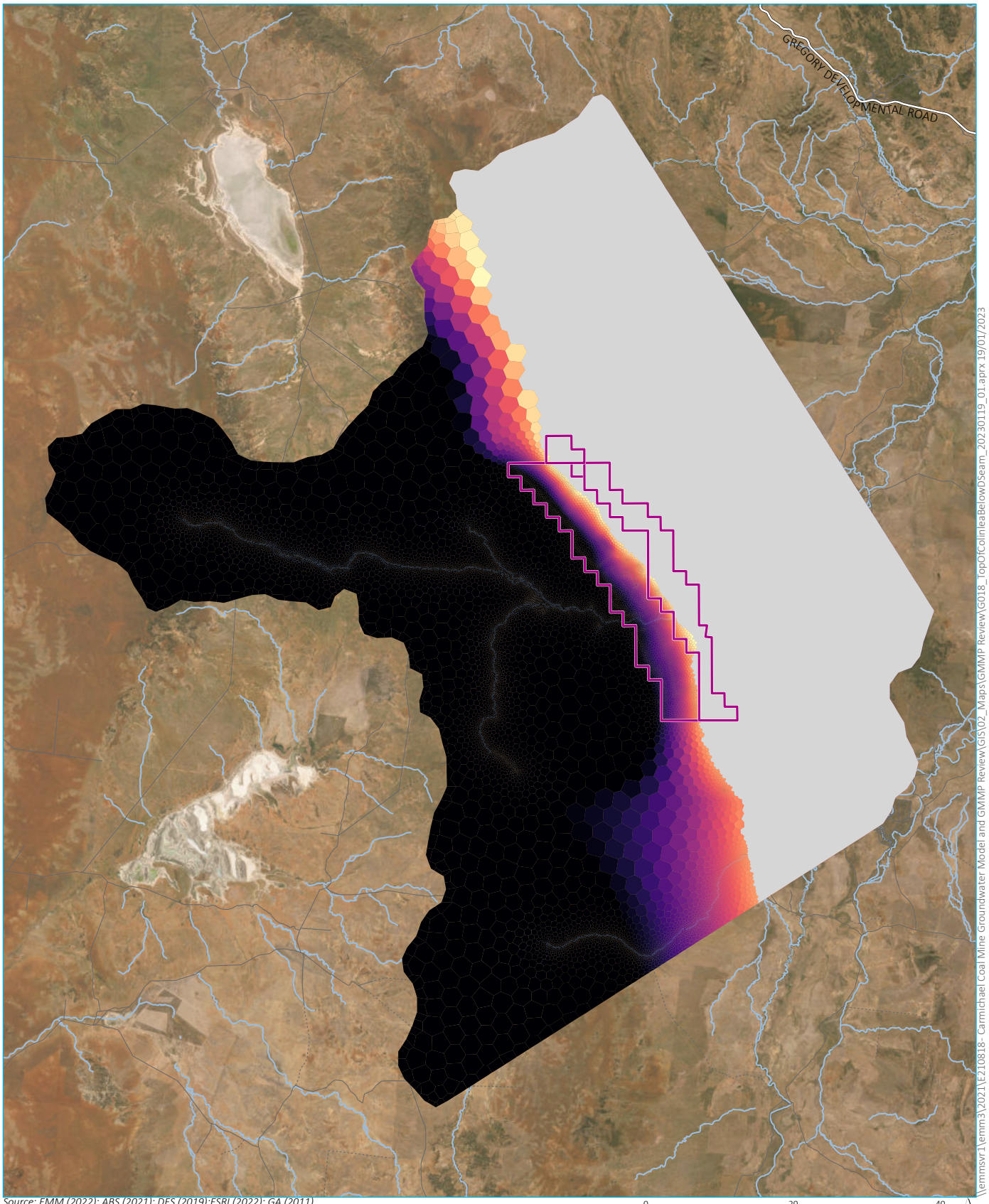
DRAFT

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

Carmichael Coal Mine
GMMP Review
Figure 3.14

EMM
creating opportunities

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G017_TopOfColinleaDseam_20230119_01.aprx 19/01/2023



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Inactive area
- Major road
- Minor road
- Vehicular track

Elevation (mAHD)

-190

220

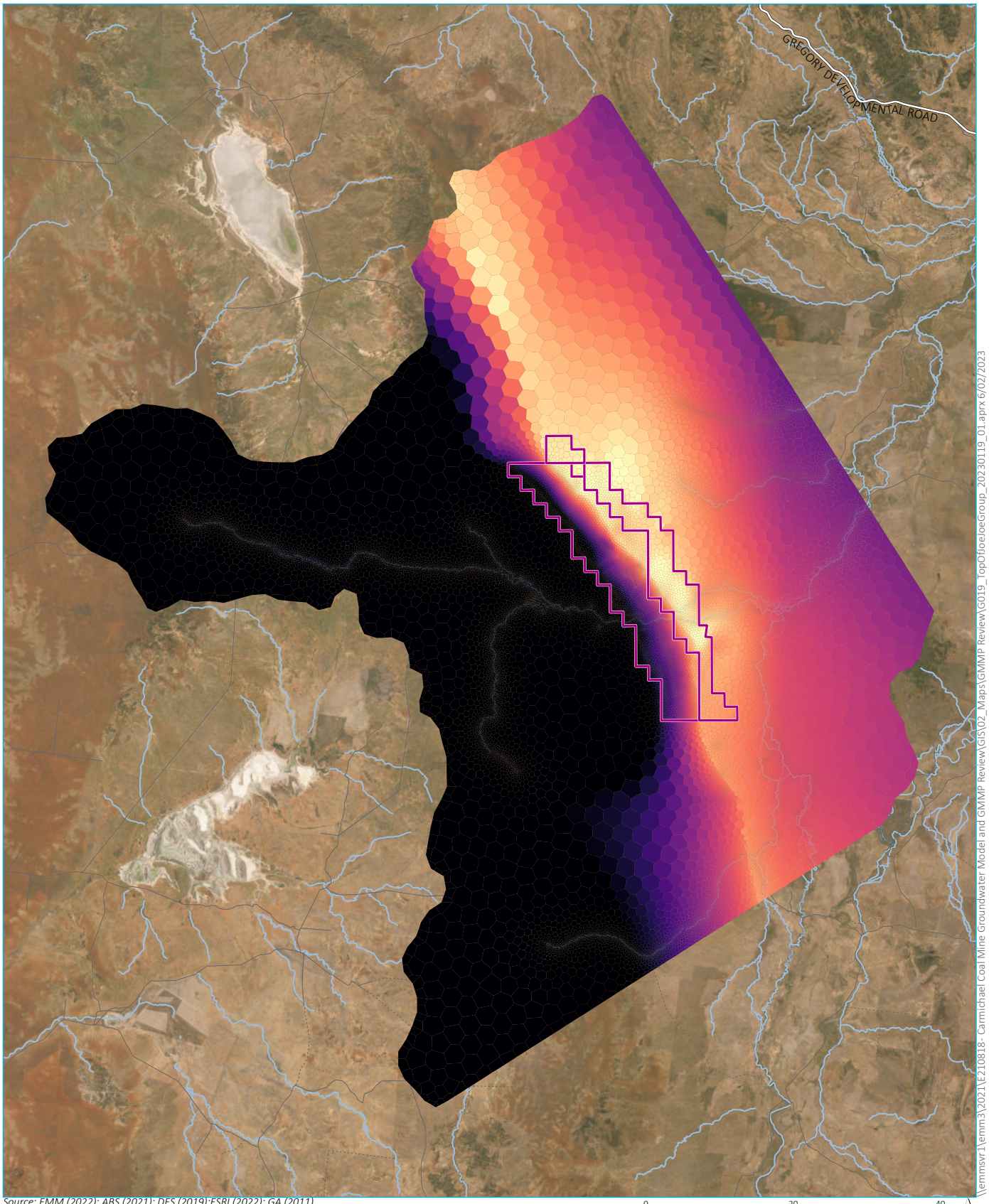
DRAFT

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

Carmichael Coal Mine
GMMP Review
Figure 3.15

EMM
creating opportunities

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G018_TopOfColinleaBelowDSeam_20230119_01.aprx 19/01/2023



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Major road
- Minor road
- Vehicular track

Elevation (mAHD)

-220

220

Top of Joe Joe Group (layer 15)

DRAFT

Carmichael Coal Mine
GMMP Review
Figure 3.16

EMM
creating opportunities

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G019_TopOfJoeJoeGroup_20230119_01.aprx 6/02/2023

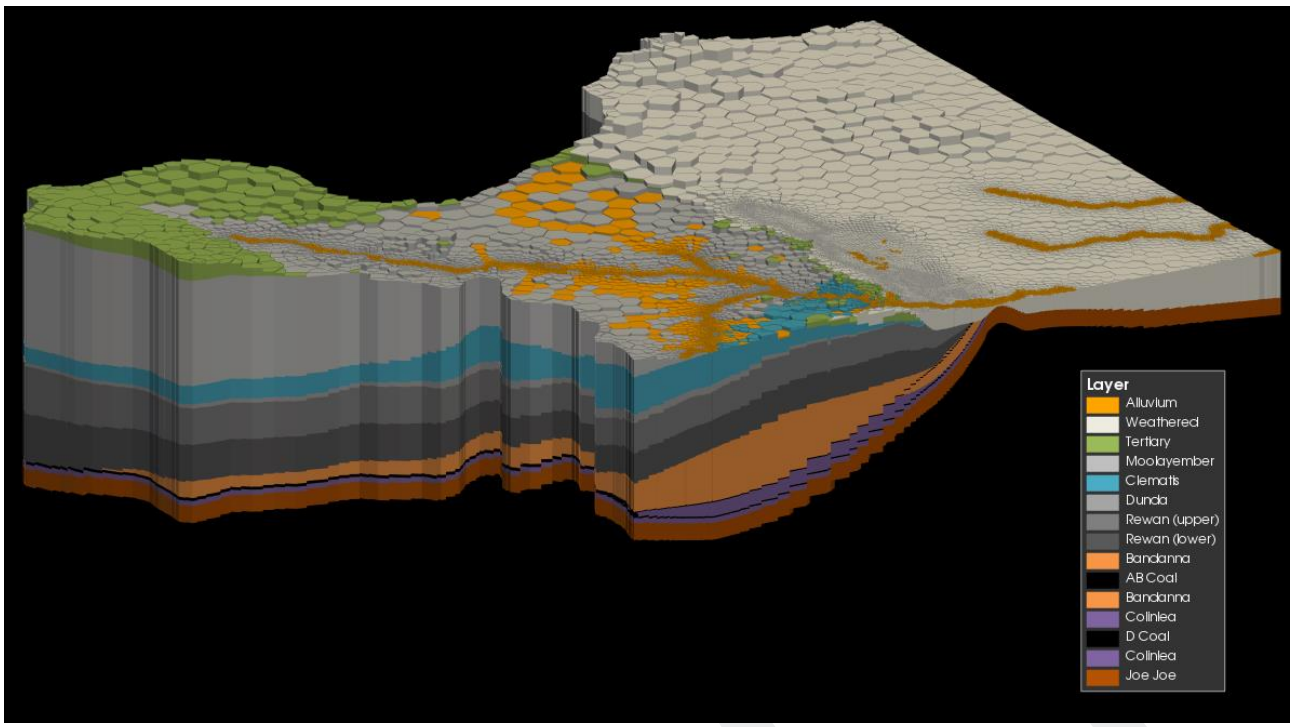


Figure 3.17 3-D visualisation of modelled HSUs

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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 x 10^{-2} m, using the χMD 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 conditions are inactive at locations where an HSU is pinched

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

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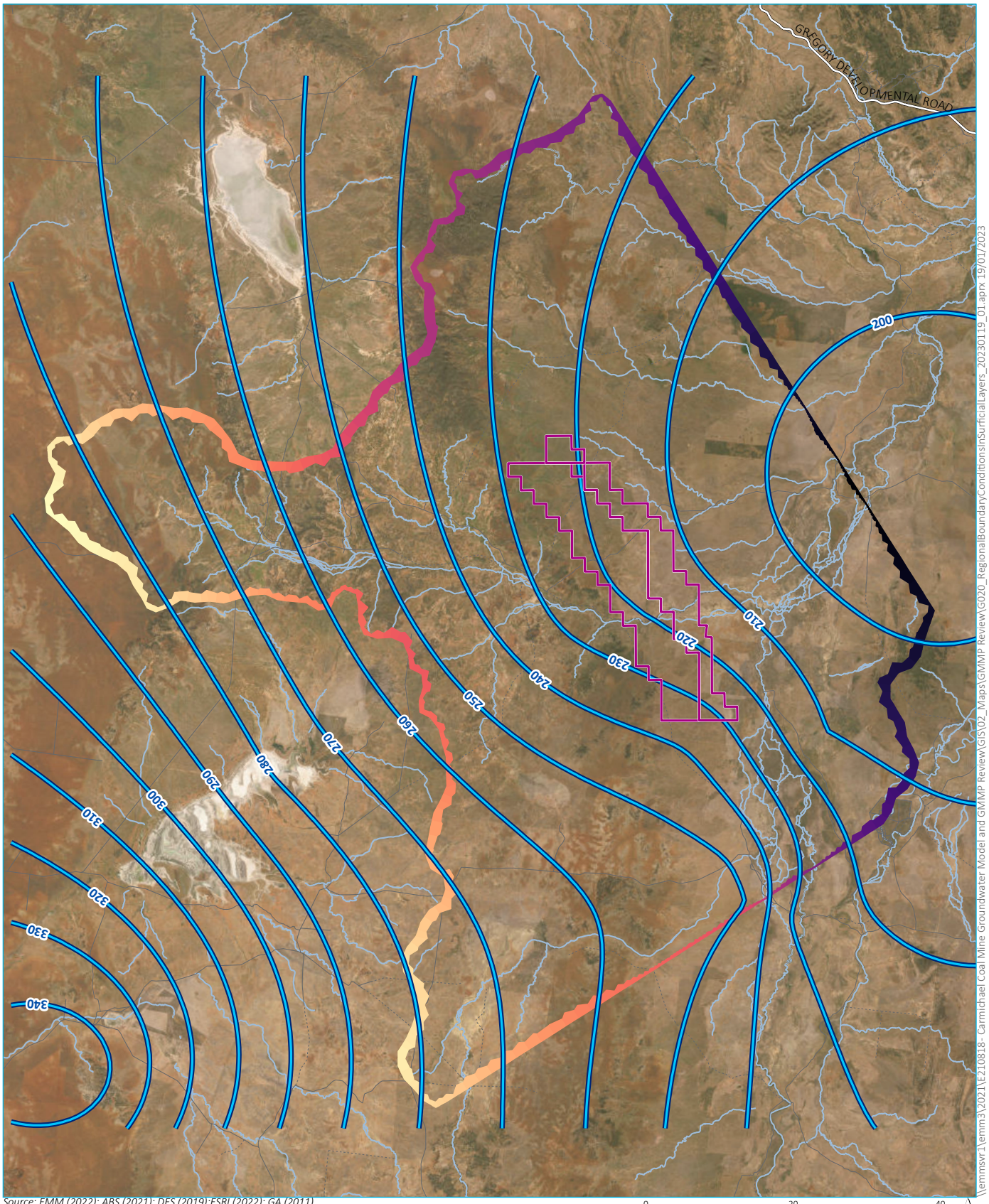


Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Major road
- Minor road
- Vehicular track
- Inferred groundwater level (mAHD)

Modelled boundary elevation (mAHD)

190

290

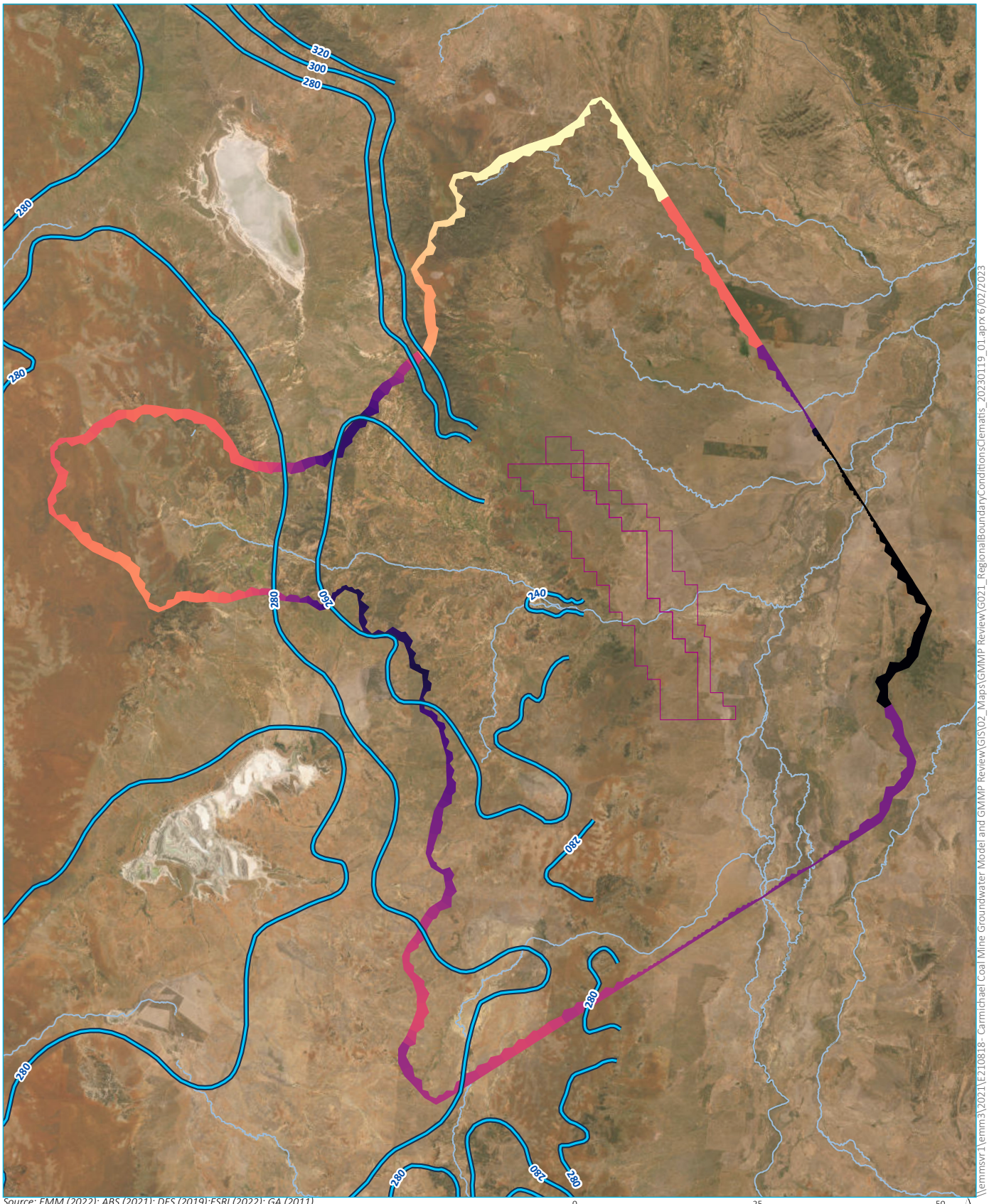
DRAFT

Modelled regional boundary conditions in surficial layers

Carmichael Coal Mine
GMMP Review
Figure 3.18

EMM
creating opportunities

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G020_RegionalBoundaryConditionsinSurficialLayers_20230119_01.aprx 19/01/2023



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 25 50 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Major watercourse
- Major road
- Inferred groundwater level (mAHD)

Modelled boundary elevation (mAHD)

250

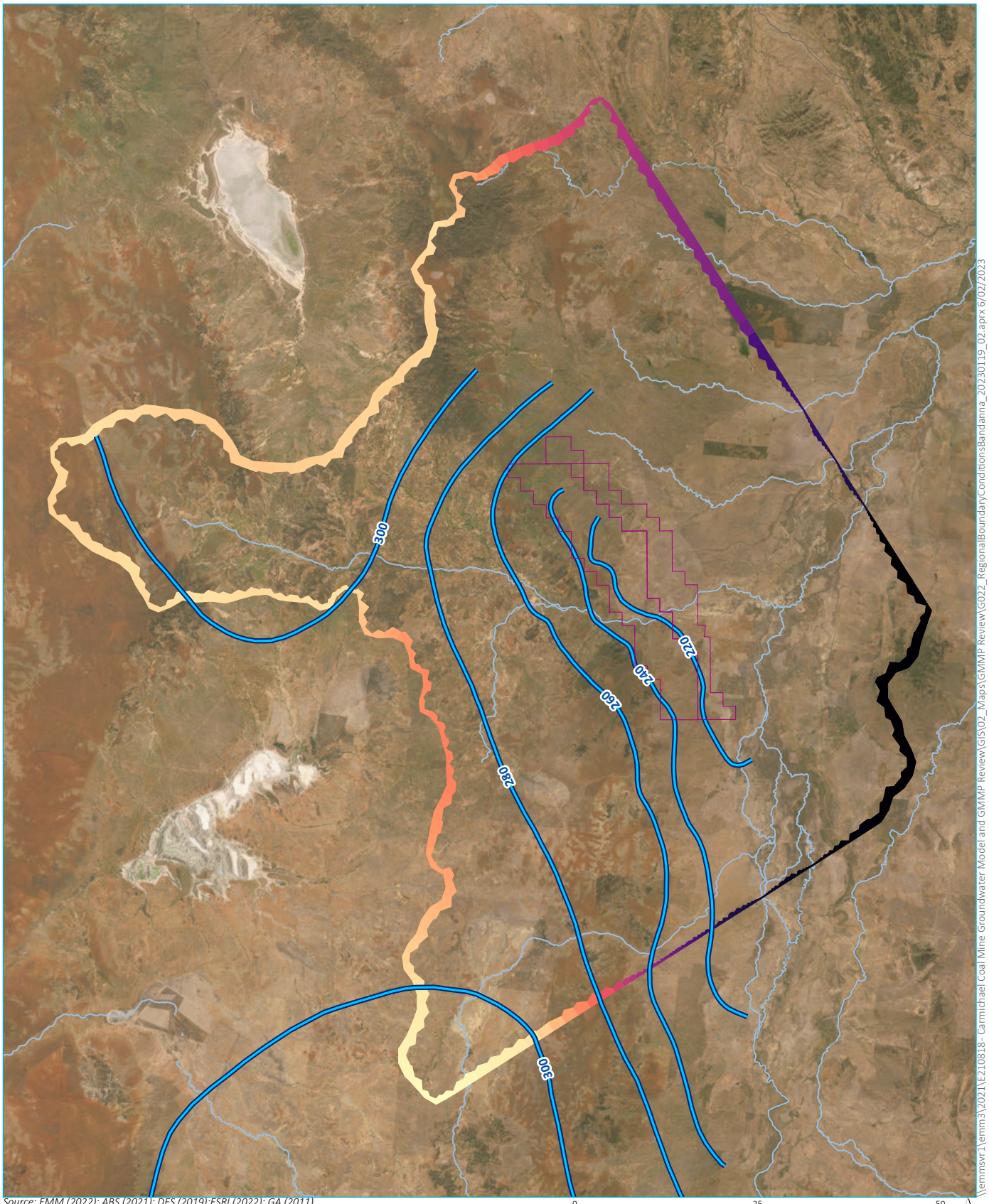
310

DRAFT

Modelled regional boundary conditions in Clematis Sandstone

Carmichael Coal Mine
GMMP Review
Figure 3.19

EMM
creating opportunities



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 25 50 km

GDA 1994 MGA Zone 55

N

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G022_RegionalBoundaryConditionsBandanna_20230119_02.aprx 6/02/2023

KEY

- Mining Lease
- Major watercourse
- Major road
- Inferred groundwater level (mAHD)

Modelled boundary elevation (mAHD)

230

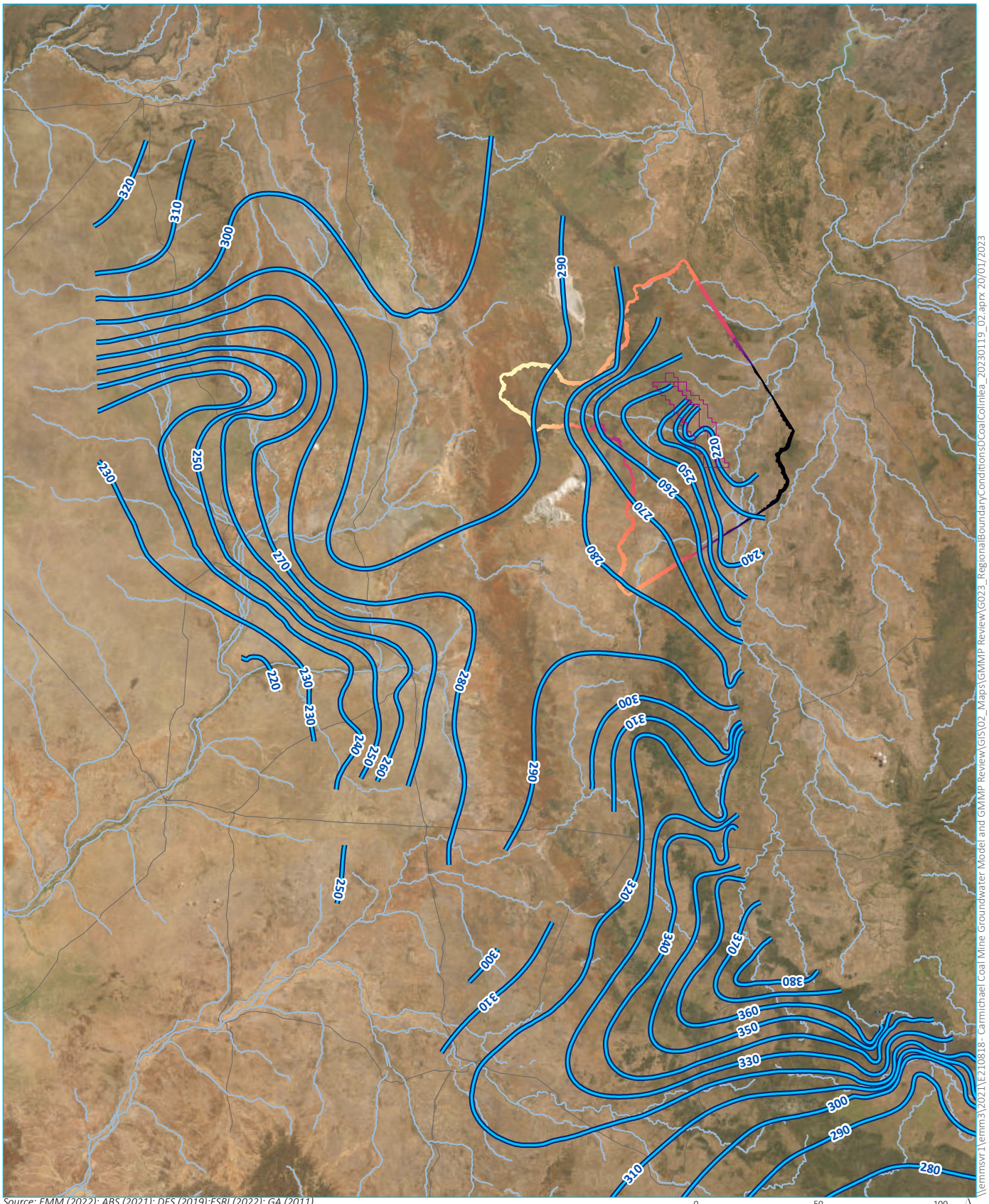
300

DRAFT

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

Carmichael Coal Mine
GMMP Review
Figure 3.21

EMM
creating opportunities



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 50 100 km

GDA 1994 MGA Zone 55

N

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G023_RegionalBoundaryConditionsDCoalColinlea_20230119_02.aprx 20/01/2023

KEY

- Mining Lease
- Major watercourse
- Major road
- Inferred groundwater level (mAHD)

Modelled boundary elevation (mAHD)

220

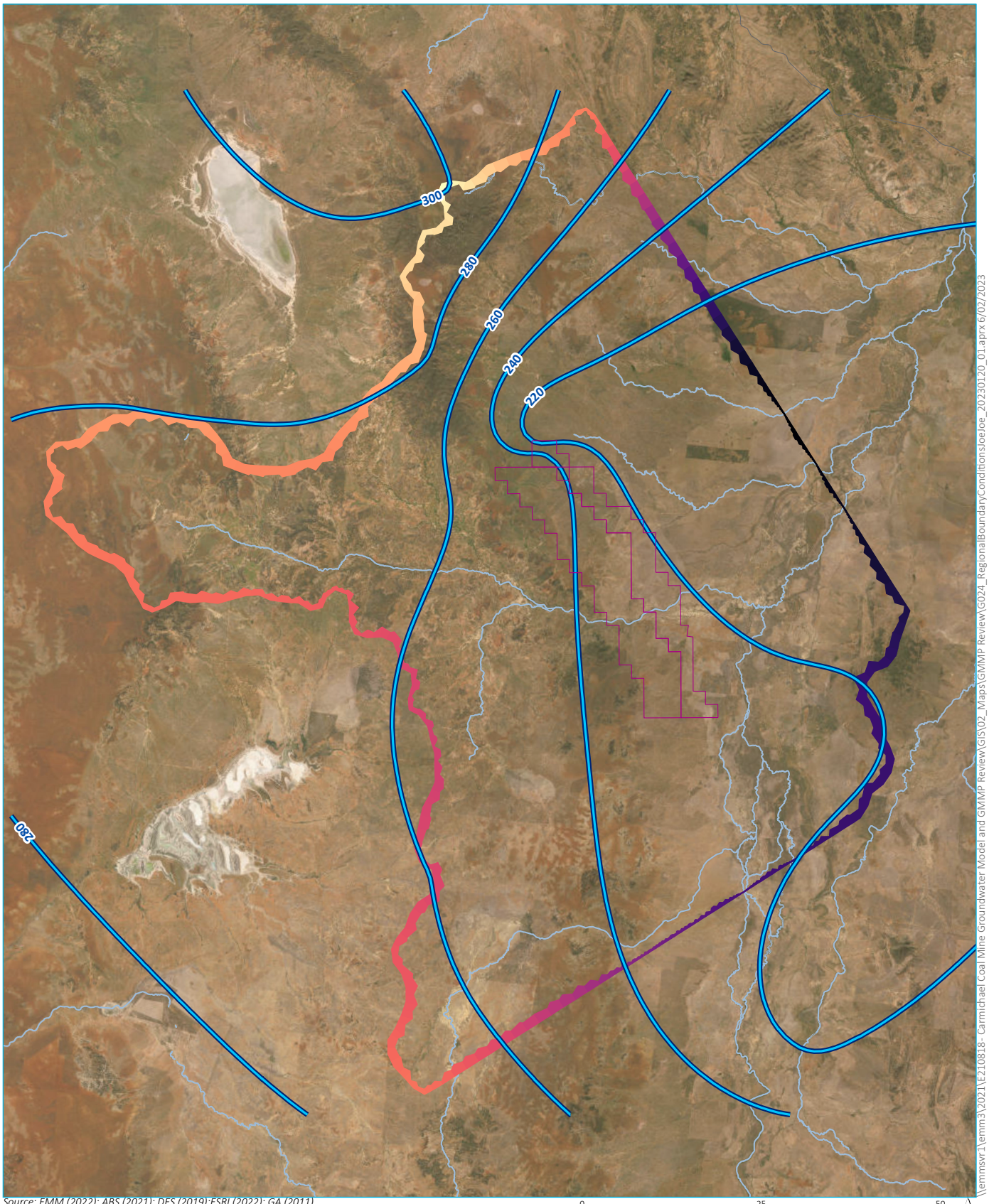
290

DRAFT

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

Carmichael Coal Mine
GMMP Review
Figure 3.21

EMM
creating opportunities



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 25 50 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Major watercourse
- Major road
- Inferred groundwater level (mAHD)

Modelled boundary elevation (mAHD)

200

300

DRAFT

Modelled regional boundary conditions in Joe Joe Group

Carmichael Coal Mine
GMMP Review
Figure 3.22

EMM
creating opportunities

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G024_RegionalBoundaryConditionsJoeJoe_20230120_01.aprx 6/02/2023

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 (also see 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
- Tomahawk Creek.

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:

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

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 m^2/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 (i.e. baseflow) 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).

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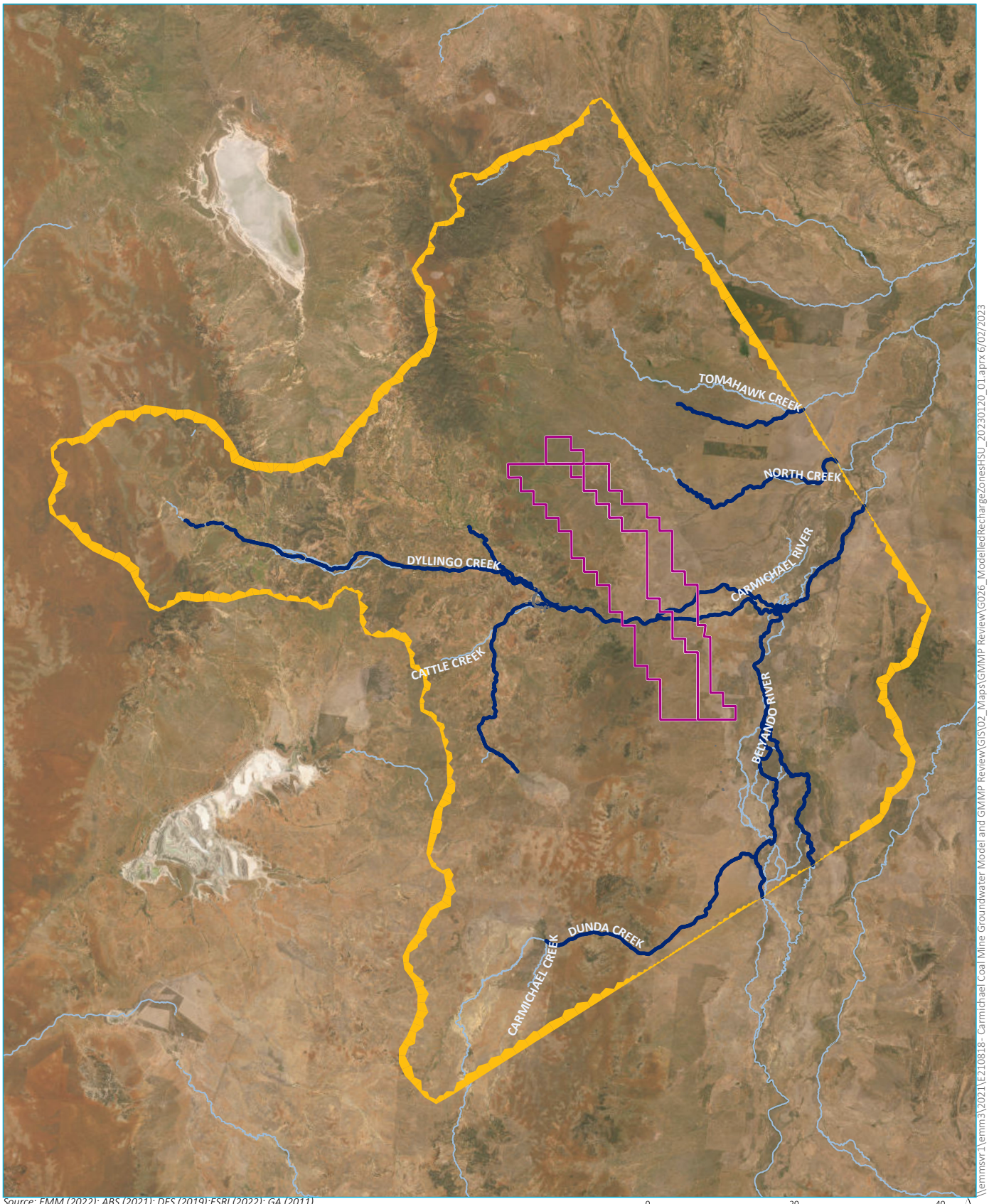

Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

\\emmsvr1\emm3\2021\E21\0818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G026_ModelledRechargeZonesHSU_20230120_01.aprx 6/02/2023

KEY

- Mining Lease
- Model river cells
- Model domain boundary
- Major watercourse
- Major road

Modelled major watercourses

DRAFT

Carmichael Coal Mine
GMMP Review
Figure 3.23

EMM
creating opportunities

Table 3.3 Modelled watercourse depths

Watercourse ID	Steady state depth (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) boundary conditions 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 condition conductance was modified during the history-matching period to approximate the hydraulic connection between the Clematis Sandstone and ground surface. This approach negates the requirement to explicitly simulate and calibrate each spring conduit during history-matching.

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 represent this, consistent with the conceptualisation by EMM (2022a), selected drain boundary conditions were modified to drain return flow cells (DRT package), where modelled discharge via the drain boundary conditions 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
- Storys.

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

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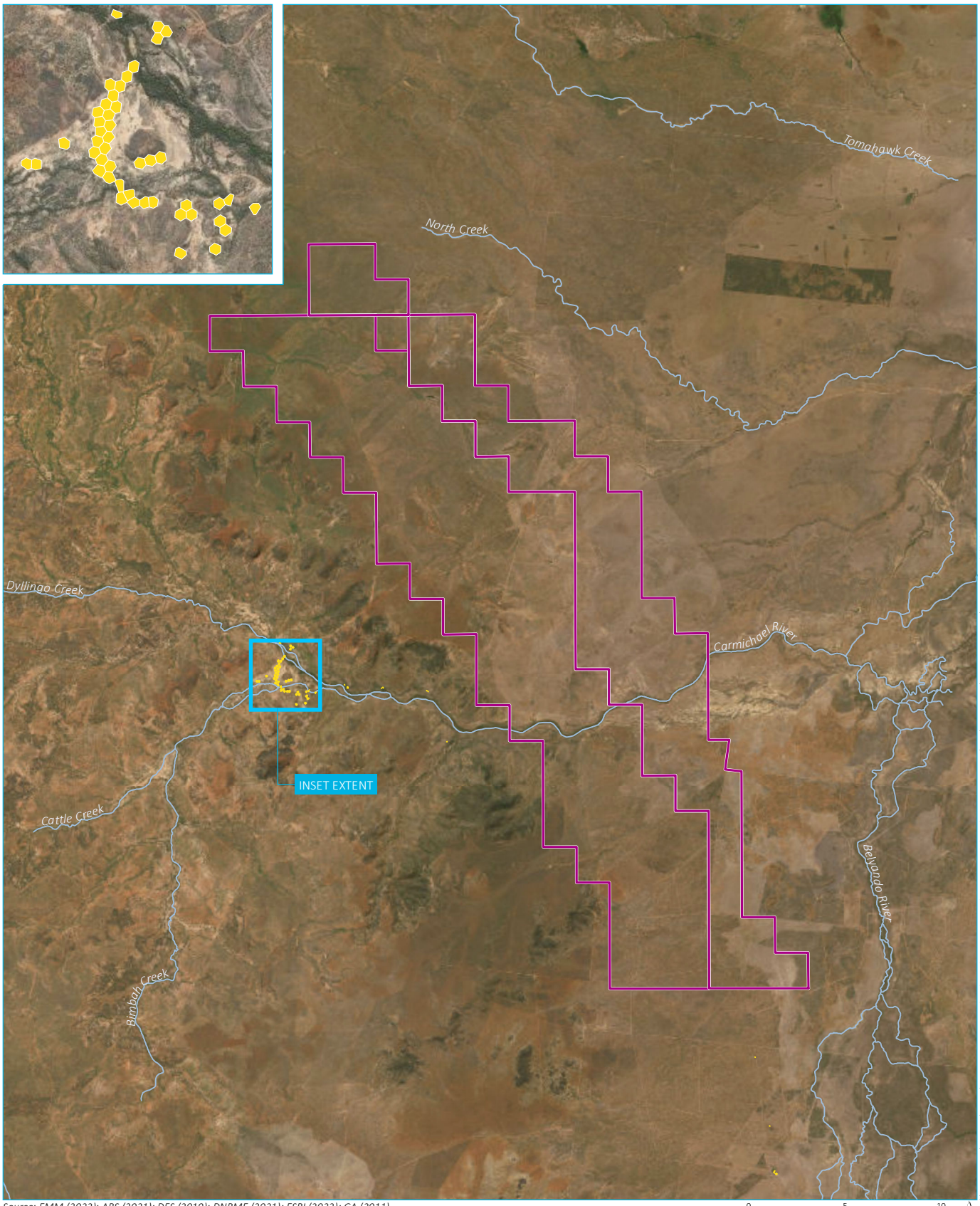

Source: EMM (2022); ABS (2021); DES (2019); DNRME (2021); ESRI (2022); GA (2011)

0 5 10 km

GDA 1994 MGA Zone 55

N

\\emmsvr1\emm3\2021\E210818 - Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G027_ModelledSprings_20230120_01.mxd 20/01/2023

KEY

- Mining lease
- Model spring cells
- Major watercourse

Modelled springs

DRAFT

Carmichael Coal Mine
GMMP Review
Figure 3.24

EMM
creating opportunities

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 (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 average annual 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
- 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.

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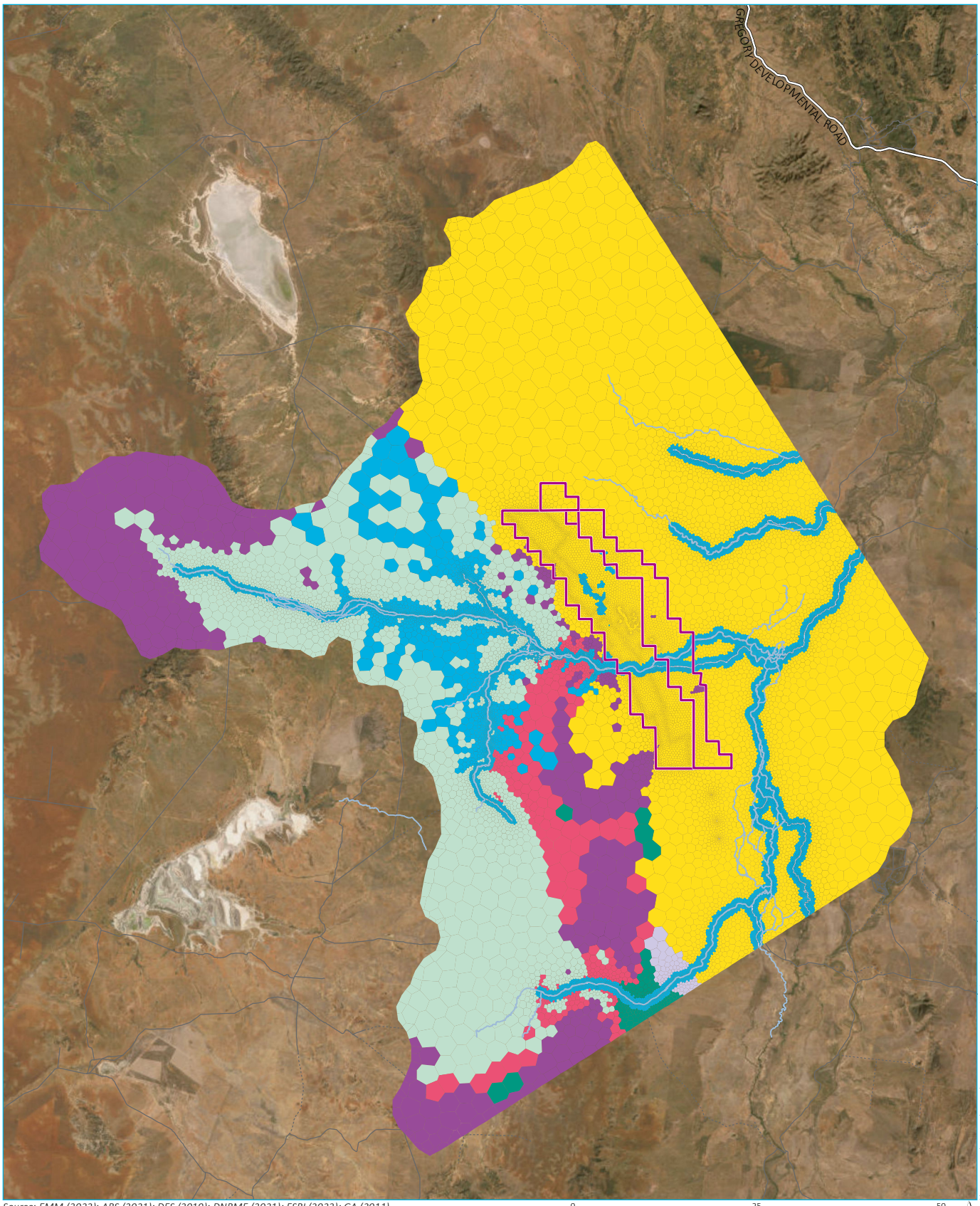

Source: EMM (2022); ABS (2021); DES (2019); DNRME (2021); ESRI (2022); GA (2011)

0 25 50 km

GDA 1994 MGA Zone 55

N

KEY

- Mining lease
- Major watercourse
- Major road
- Minor road
- Vehicular track

Outcropping HSU

- Alluvium
- Weathering zone
- Tertiary and non-alluvial Quaternary
- Moolayember Formation
- Clematis Sandstone/ Warang Sandstone
- Rewan Formation
- Permian

DRAFT

Modelled recharge zones based on outcropping HSU

Carmichael Coal Mine
GMMP Review
Figure 3.25

EMM
creating opportunities

\\emmsvr1\emm3\2021\E210818 - Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G029_ModelledProductionBores_20230123_01.mxd 23/01/2023

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 when groundwater responses have been measured, though the averaging over a month reduces the modelled influence of individual rainfall events.

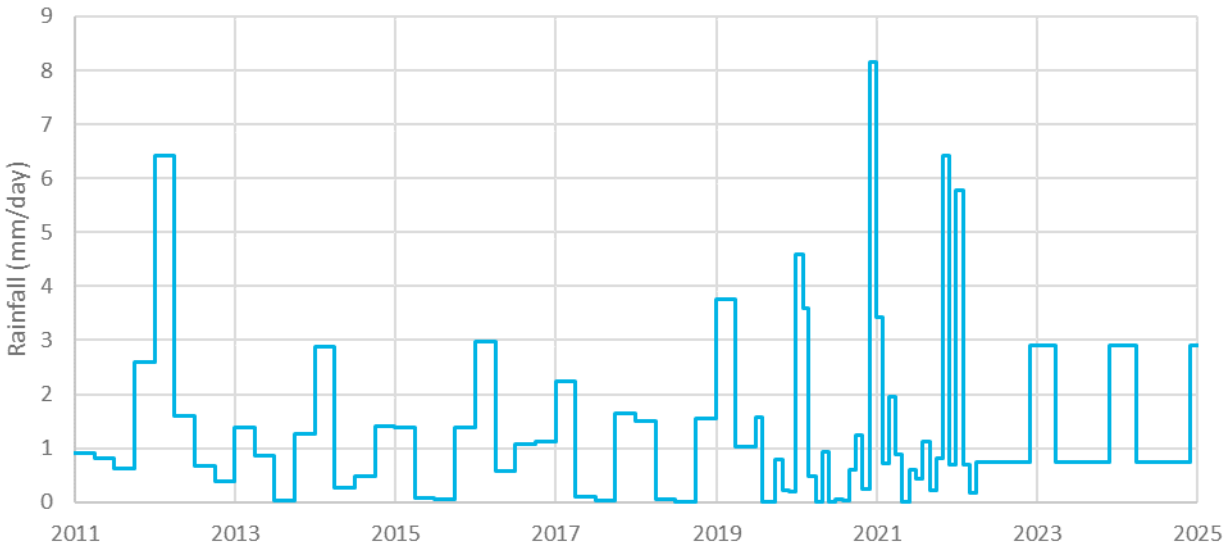

Figure 3.26 Modelled rainfall time series used to inform rainfall-derived recharge

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, 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 was applied for the majority of the model domain. This depth is consistent with grass cover on sandy soil Shah et al. (2007). A second evapotranspiration zone is employed adjacent to surface water features to represent increased vegetation cover and rooting depth, with an extinction depth of 6 m applied. 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 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							

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
2021			Active							
2022			Active							
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 from each bore is simulated using 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 conditions (refer Section ii) and, therefore, there are no groundwater abstraction bores 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. Mine progression is simulated in accordance with the provided staged mine plan (refer Appendix D) for the predictive period, with boundary conditions 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 m^2/d). The cells assigned DRN boundary conditions at the end of mining are presented in Figure 3.30.

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

Prediction stress periods (refer Table 3.2) employ a higher temporal resolution, to simulate the dynamic equilibrium of the groundwater system between wet and dry seasons, than the schedule for the mine plan. Activation of mine dewatering DRN boundary conditions 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 with regard to predicting drawdown (Section 5.3).

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iii Mining-induced property changes

Longwall 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 used, following GHD (2013b) and Merrick (2021), to allow for direct comparison against the existing groundwater model and updated for current estimates respectively.

The fracturing property changes adopted by GHD (2013) include modification of hydraulic conductivity for cells within 150 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 mining, 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.

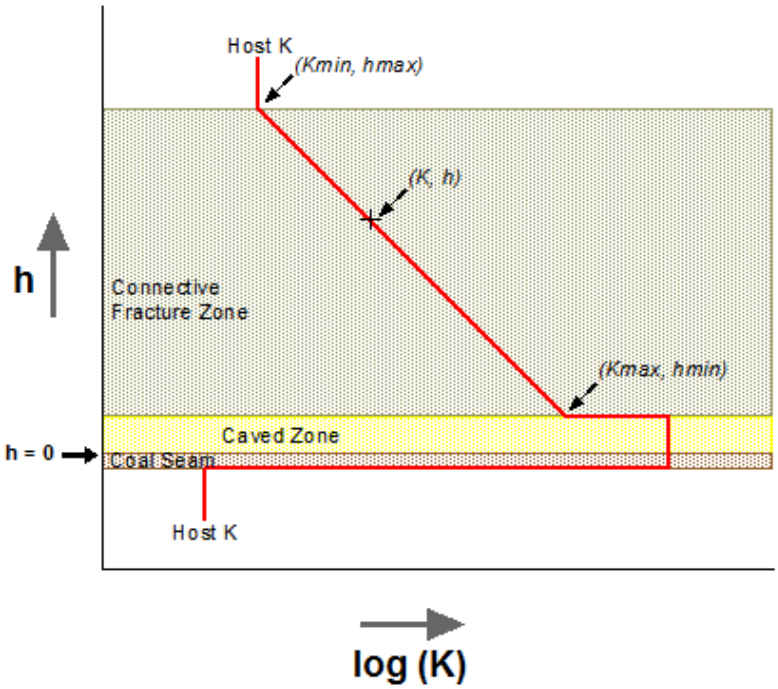

Figure 3.27 Ramp function parameters

Hydraulic conductivity in the connective fracture zone is calculated by:

$$K = 10^{\left(\log(Kmax) - \frac{\log(Kmax)-\log(Kmin)}{hmax-hmin}(h-hmin)\right)}$$

Parameters for the updated model are as follows:

- *Kmax* = 5 m/d
- *Kmin* = background (calibrated) hydraulic conductivity
- *hmax* = 230 m
- *hmin* = 0 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).

iv Post-mine recovery

At the end of mining, modelled drain boundary conditions representing 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 the 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 those of a 'void' at the cessation of mining. This package assigns multipliers 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 TVM package is also applied at model nodes representing backfill, with final horizontal and vertical hydraulic conductivity values of 0.5 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 the 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 modelled water level drops below the bottom of a well, no water is abstracted, mimicking evaporation.
- 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.

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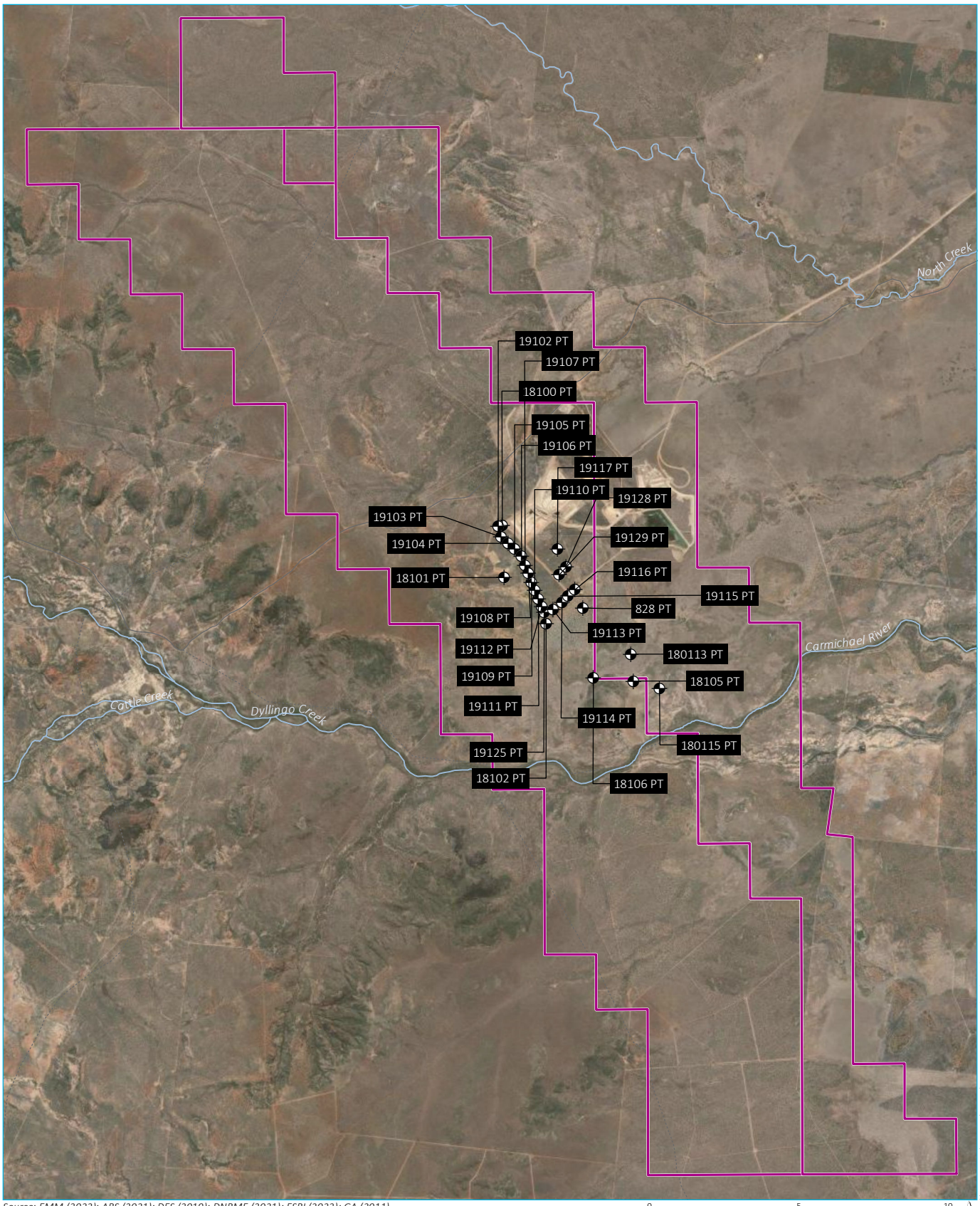

Source: EMM (2022); ABS (2021); DES (2019); DNRME (2021); ESRI (2022); GA (2011)

0 5 10 km

GDA 1994 MGA Zone 55

N

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KEY

- Mining lease
- Modelled production bores
- Major watercourse
- Minor road
- Vehicular track

DRAFT

Modelled production bores

Carmichael Coal Mine
GMMP Review
Figure 3.28

EMM
creating opportunities

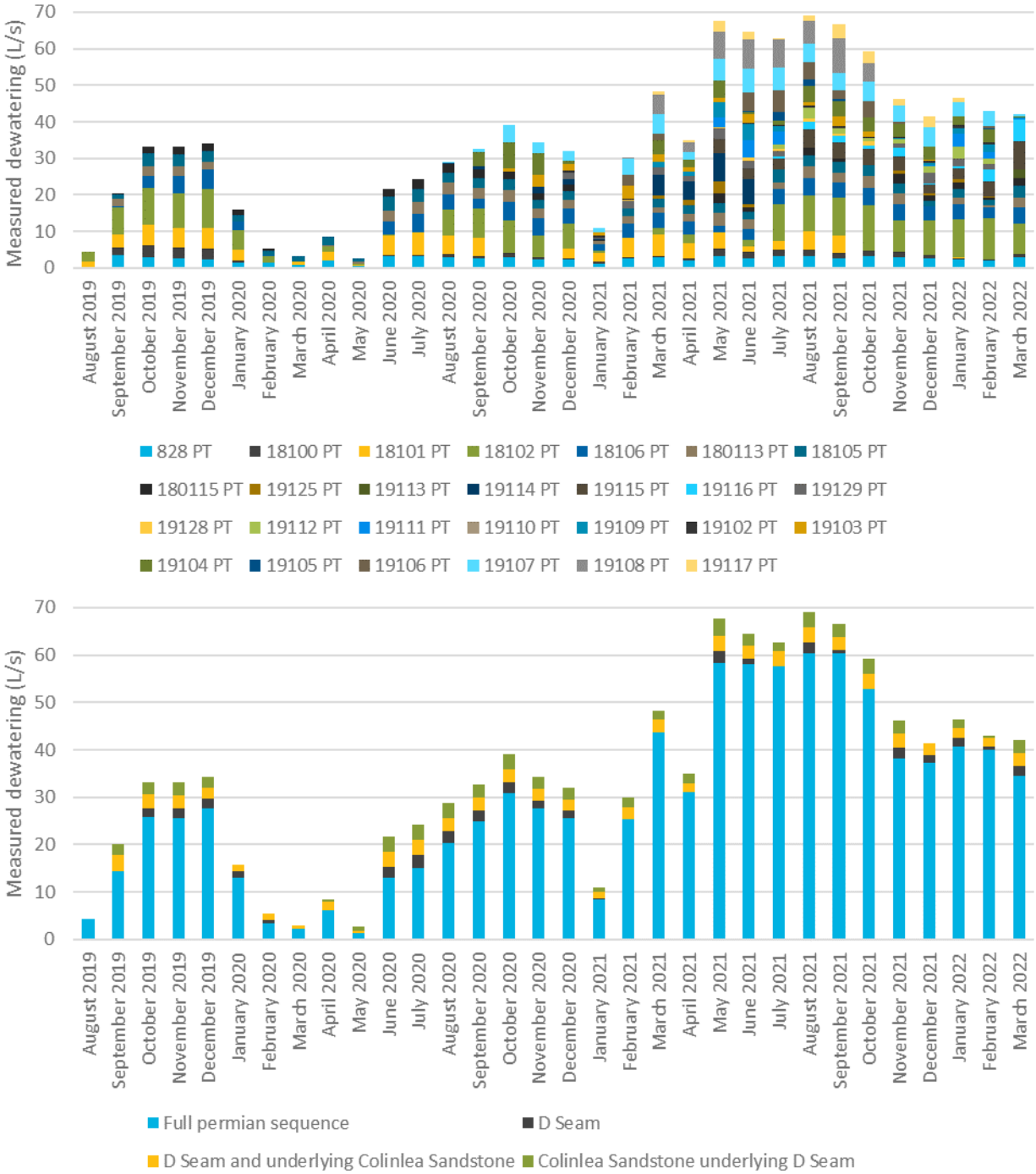
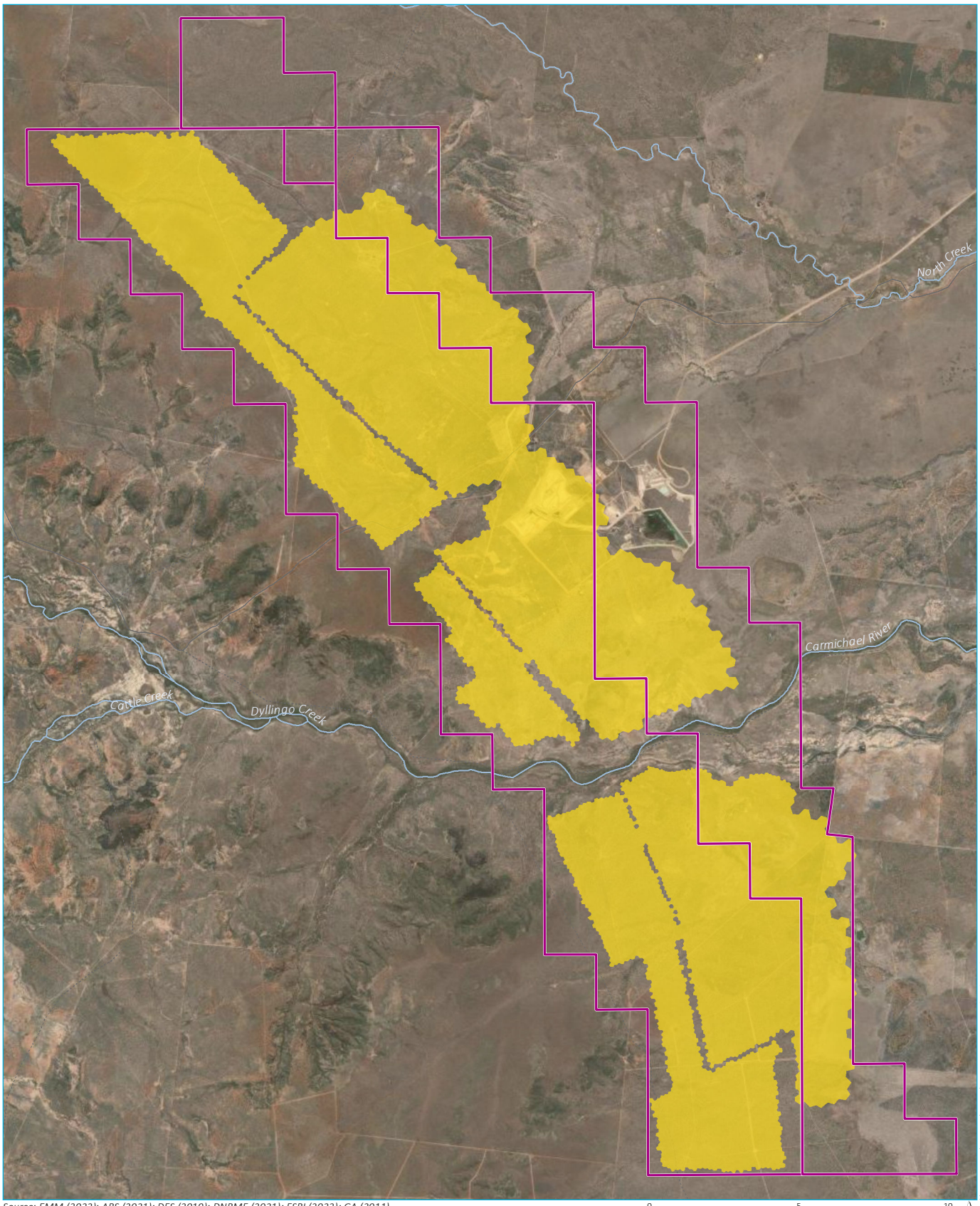


Figure 3.29 Measured abstraction from production bores



Source: EMM (2022); ABS (2021); DES (2019); DNRME (2021); ESRI (2022); GA (2011)

0 5 10 km

GDA 1994 MGA Zone 55

N

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KEY

- Mining lease
- Modelled mine dewatering cells
- Major watercourse
- Minor road
- Vehicular track

Modelled drain cells at the end of mining

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Carmichael Coal Mine
GMMP Review
Figure 3.30

EMM
creating opportunities

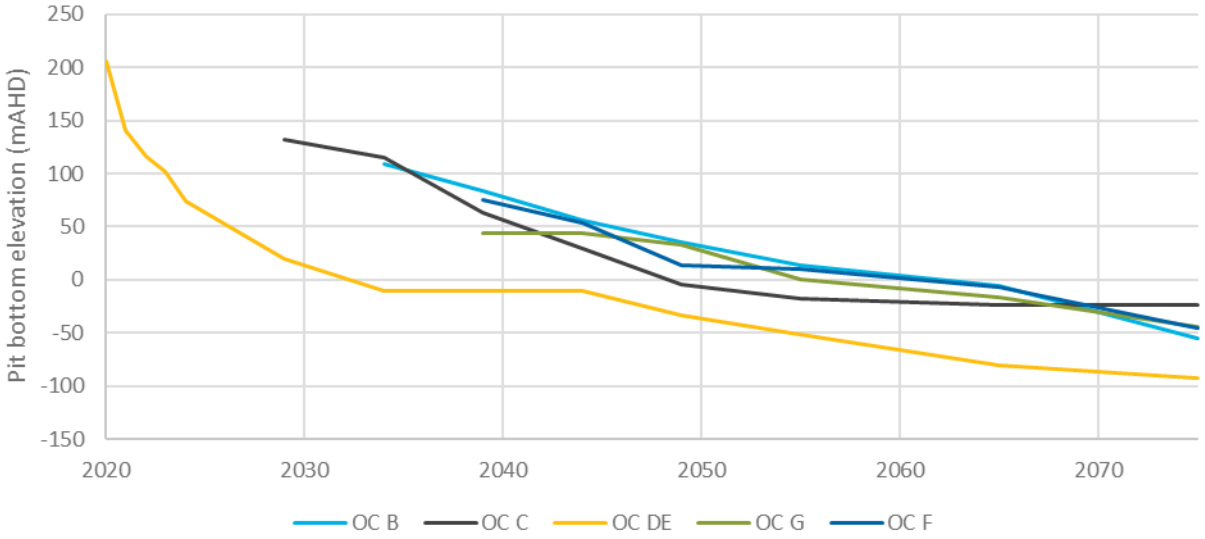


Figure 3.31 Open cut pit bottom elevations

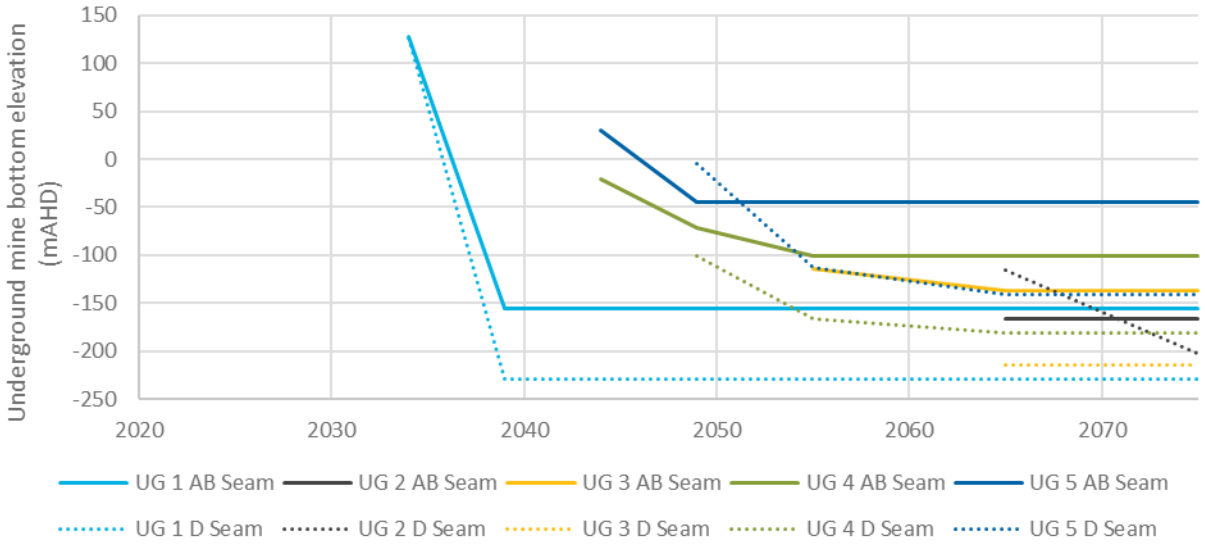
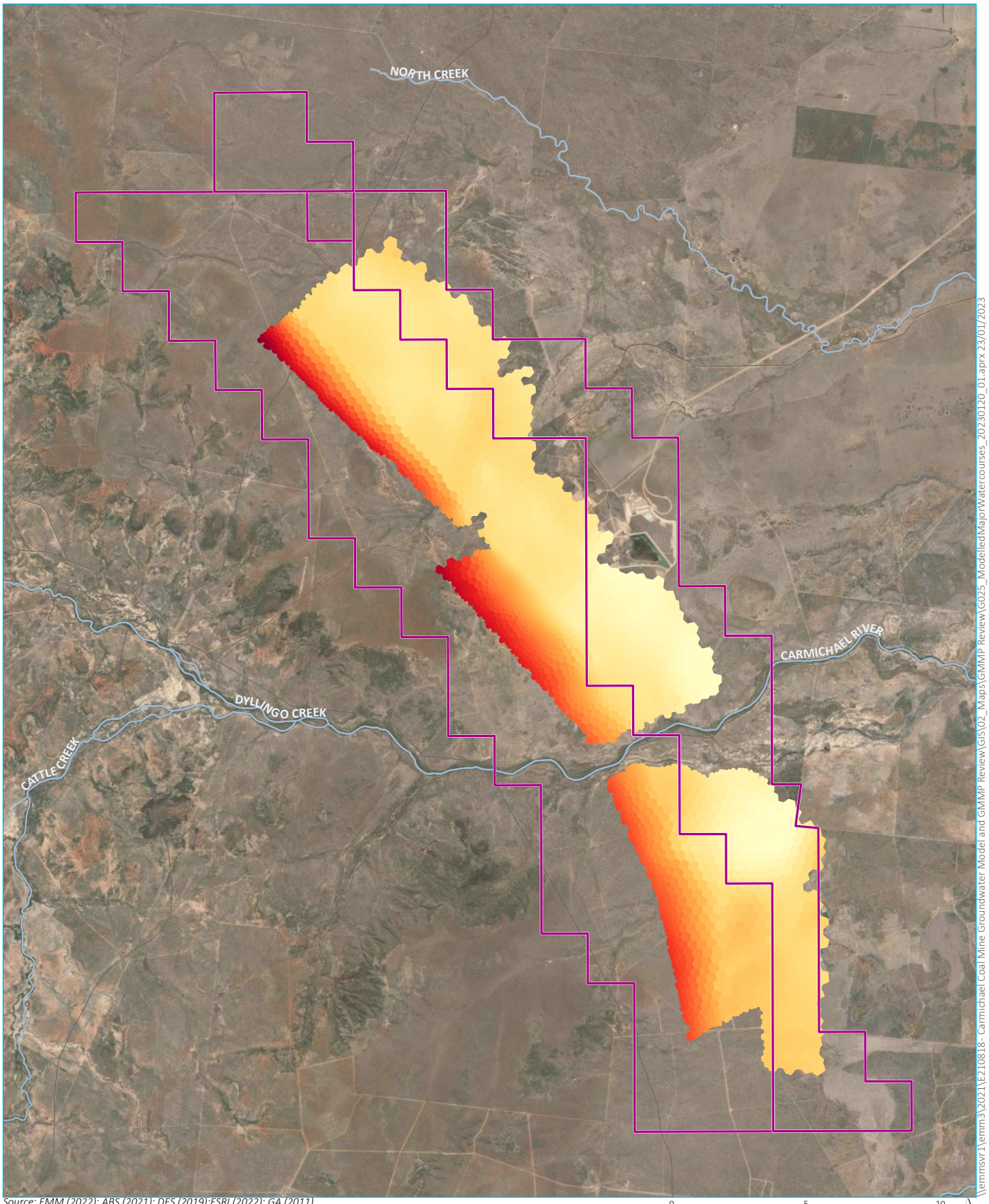


Figure 3.32 Underground mine bottom elevations



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 5 10 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Major watercourse
- Major road

Pit void depth

3.9

310

Modelled post-mining pit void depth

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Carmichael Coal Mine
GMMP Review
Figure 3.33

EMM creating opportunities

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4 History-matching

4.1 Approach

A combination of manual and automated approaches were employed during the history-matching process using PESTPP-IES (White et al 2020) This software optimises an ensemble of random model parameter realisations on an iterative basis, making an estimate of the Jacobian matrix (which is used by the older versions of PEST software) 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. Spring flux targets were included to ensure consistency between water balance modelling and the numerical groundwater flow model.

Initially, the model was calibrated using a single parameter value for each hydraulic property per HSU (i.e. a traditional 'zoned' approach to parameterisation). 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, 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 levels and dynamics, both from climatic stresses and mine dewatering. Groundwater measurements were taken from manual readings and loggers; these were separated into separate target groups. Logger data were resampled to monthly measurements to reduce the volume of target data (where/when they were not contributing additional information on system behaviour).

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 limited 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
- 2 flux targets.

PESTPP-IES 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.

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Each measurement within a target group therefore had the same weight applied. Weights of hydraulic head targets were increased by a factor of √2 to double their relative contribution to the objective function.

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

The locations of monitoring bores from which history-matching targets were employed are presented in Figure 4.1, categorised by HSU.

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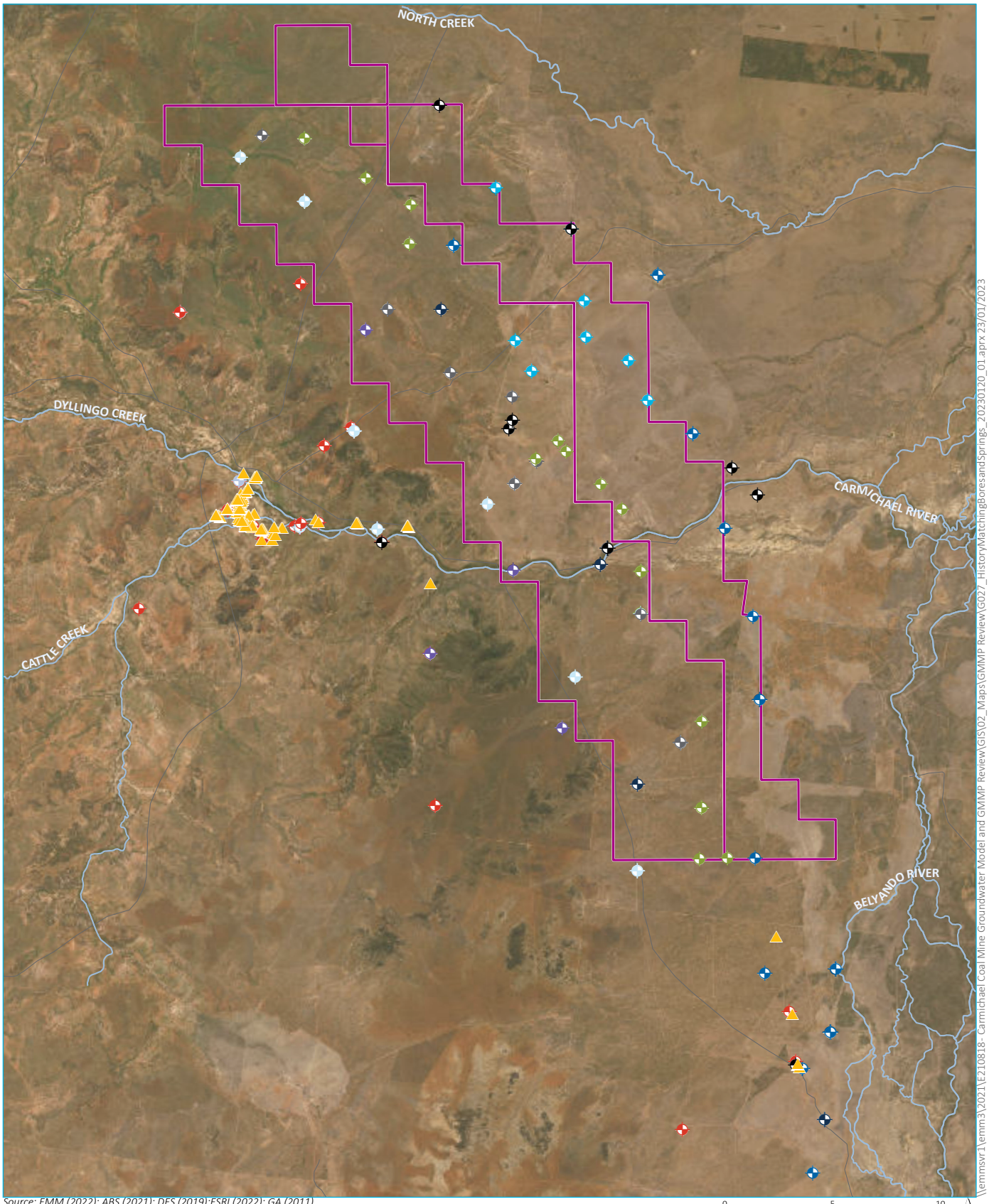

Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 5 10 km
GDA 1994 MGA Zone 55
N

History-matching target bores and springs

KEY

- Mining Lease
- Spring
- Major watercourse
- Major road

Target bore

- Alluvium
- Weathering zone
- Tertiary and non alluvial Quaternary
- Moolayember Formation
- Clematis Sandstone/ Warang Sandstone
- Dunda Beds
- Rewan Formation
- Bandanna Formation
- Colinlea Sandstone
- Joe Joe Group

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Carmichael Coal Mine
GMMP Review
Figure 4.1

EMM
creating opportunities

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G027_HistoryMatchingBoresandSprings_20230120_01.aprx 23/01/2023

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
- pumping from 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 employed by PESTPP-IES to calculate the Jacobian matrix is extremely efficient when compared to other versions of PEST and, as a result, there is no effective limit on the number of pilot points that can be incorporated in the history-matching process. A triangulation algorithm was employed to place pilot points between targets (including dewatering 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 (DRN package) conductance (Section 3.5.2i) and zoned recharge (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 properties of the prior (i.e. pre-history-matching) probability distribution of parameters. These take 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 were:

- all HSU hydraulic properties (horizontal and vertical hydraulic conductivity, specific storage, specific yield)
- all spring (Drain) conductances
- all zoned groundwater recharge rates.

A 500-realisation ensemble of parameter values was developed as the 'prior' parameter ensemble, and several optimisation iterations, via PESTPP-IES, were employed to develop a parameter field minimising the residuals between modelled and measured values. 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 for predictive uncertainty analysis (Section 5.3).

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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. Detailed documentation of all history-matched parameter values for the the adopted ensemble of realisations is provided in Appendix B.

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 predicting 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 full ensemble of adopted realisations based on 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).

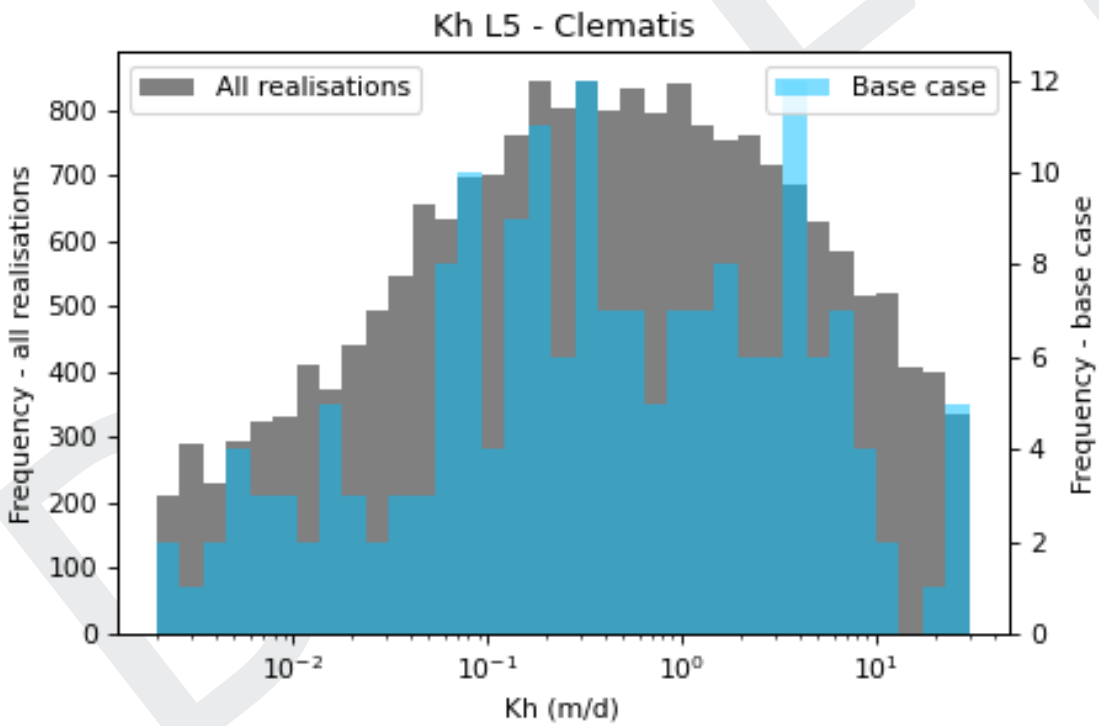
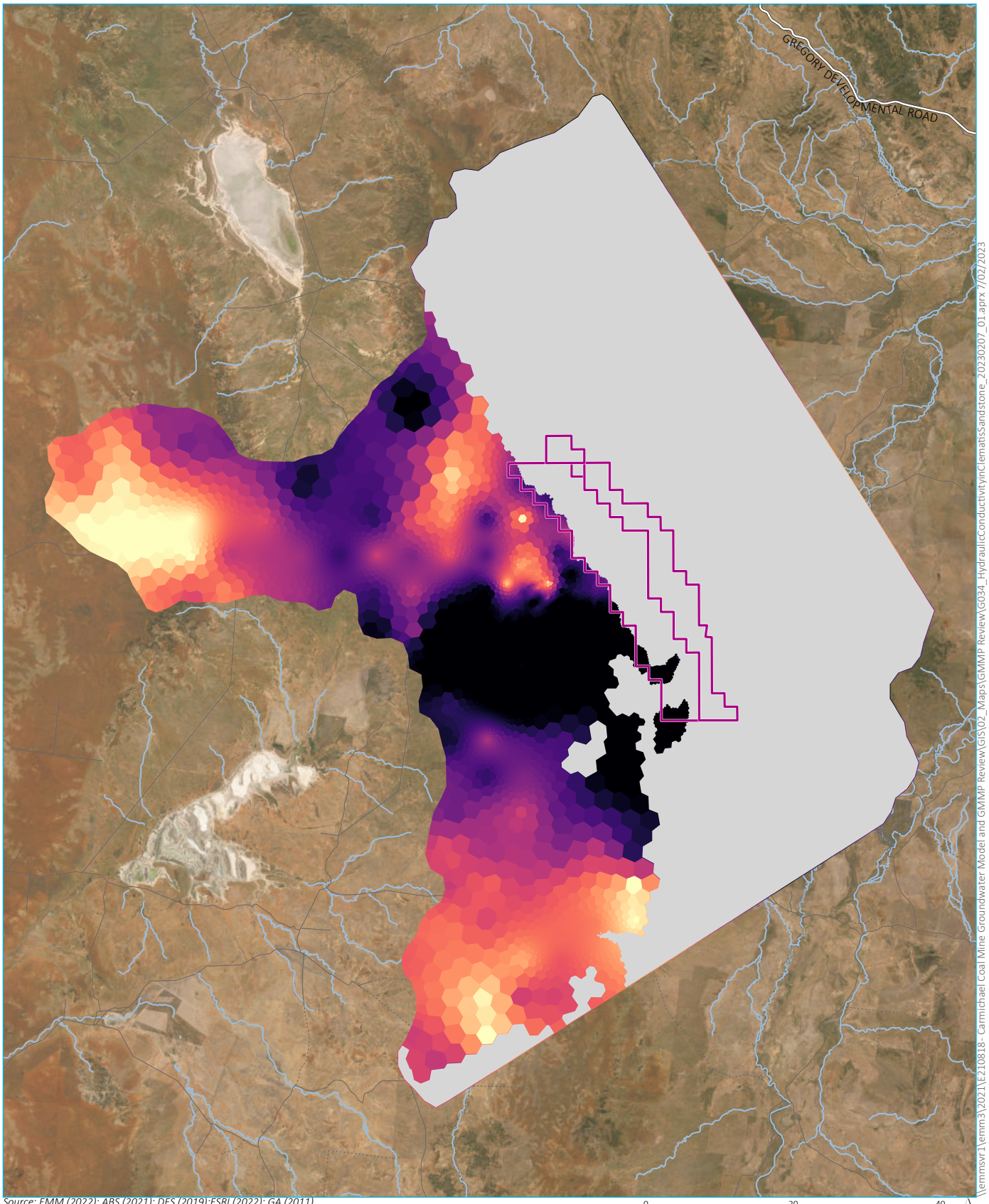


Figure 4.2 Kh pilot point parameter frequency distribution for Clematis Sandstone across base realisation and full ensemble of adopted realisations

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 immediately south of the Carmichael River is simulated with lower hydraulic conductivities, below 0.1 m/day.



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Inactive area
- Major road
- Minor road
- Vehicular track

Log of hydraulic conductivity (m/d)

-2.7

3.3

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Base realisation modelled horizontal hydraulic conductivity in Clematis Sandstone

Carmichael Coal Mine
GMMP Review
Figure 4.3

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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 and hydraulic gradients 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 x 10^{-6} and 1 x 10^{-5} m/day for the upper profile and around 1 x 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 x 10^{-9} m/day.

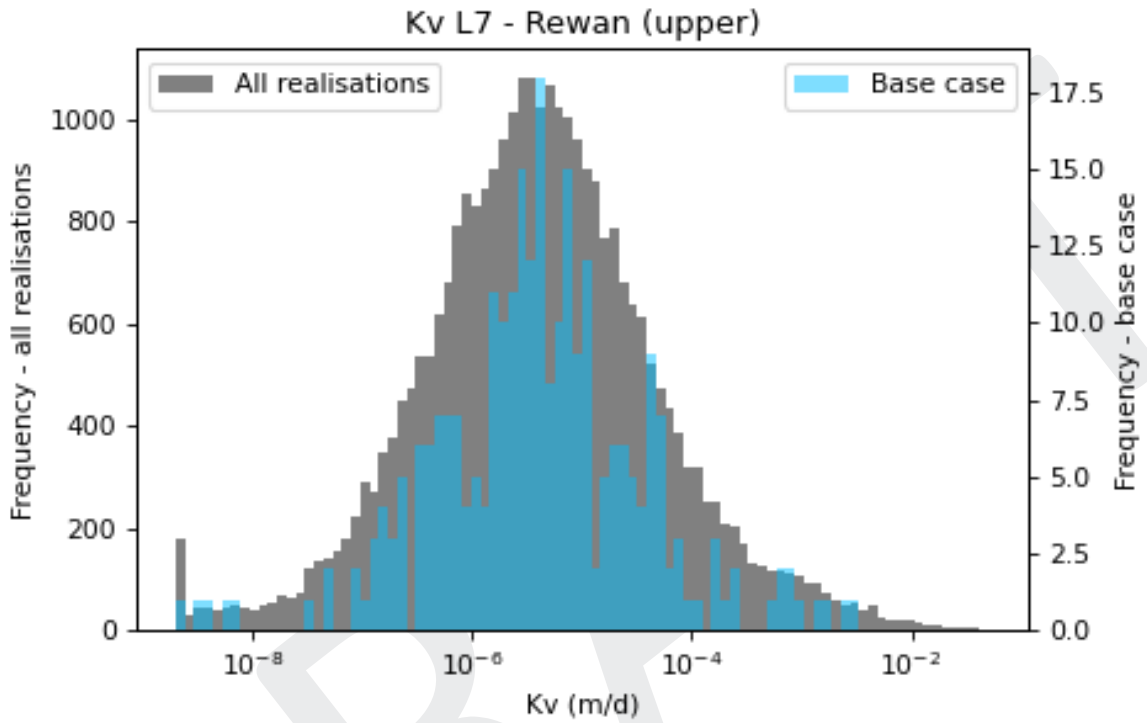

Figure 4.4 Kv pilot point parameter frequency distribution for upper Rewan Formation across base realisation and full ensemble of adopted realisations

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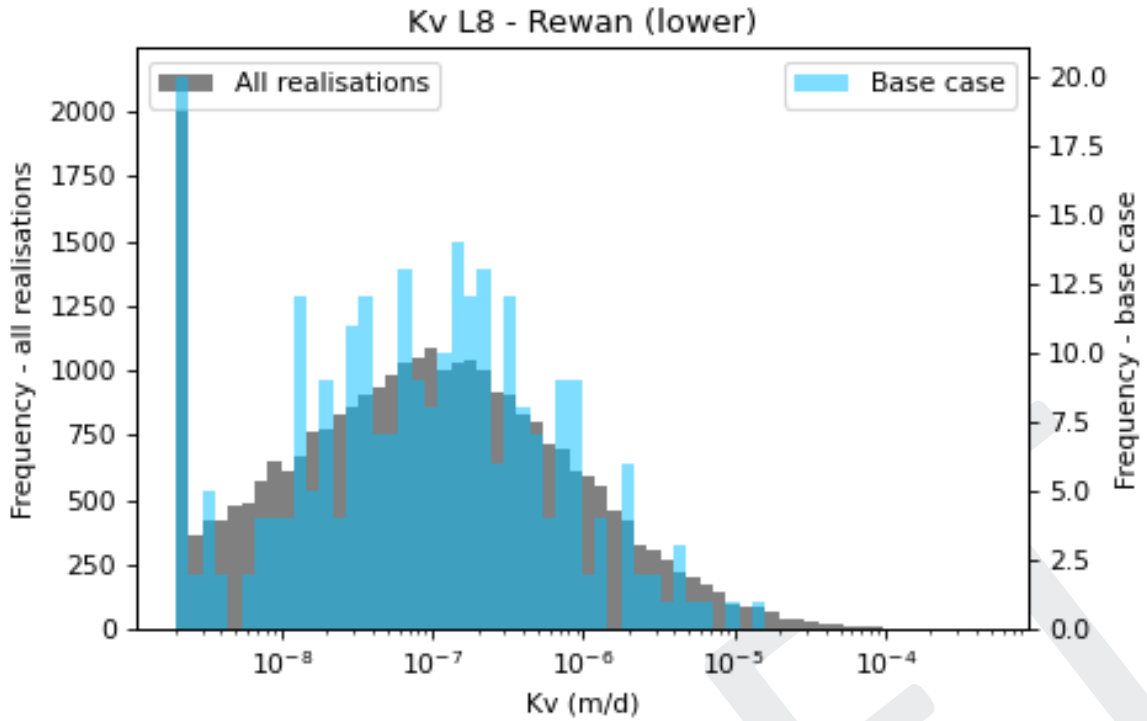

Figure 4.5 **Kv pilot point parameter frequency distribution for lower Rewan Formation across base realisation and full ensemble of adopted realisations**

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.

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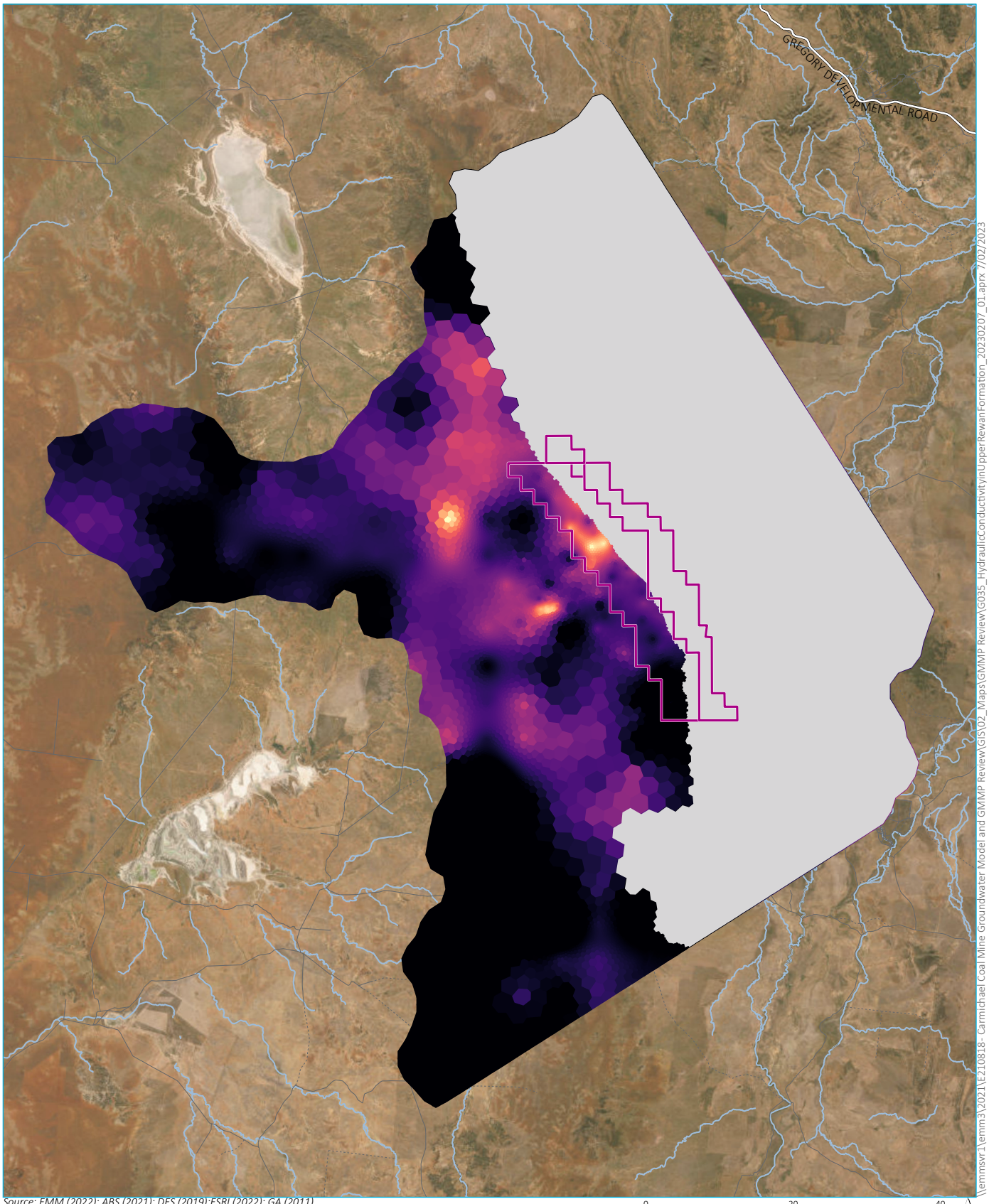

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Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Inactive area
- Major road
- Minor road
- Vehicular track

Log of hydraulic conductivity (m/d)

-14

-6.5

DRAFT

Base realisation modelled vertical hydraulic conductivity in upper Rewan Formation

Carmichael Coal Mine
GMMP Review
Figure 4.6

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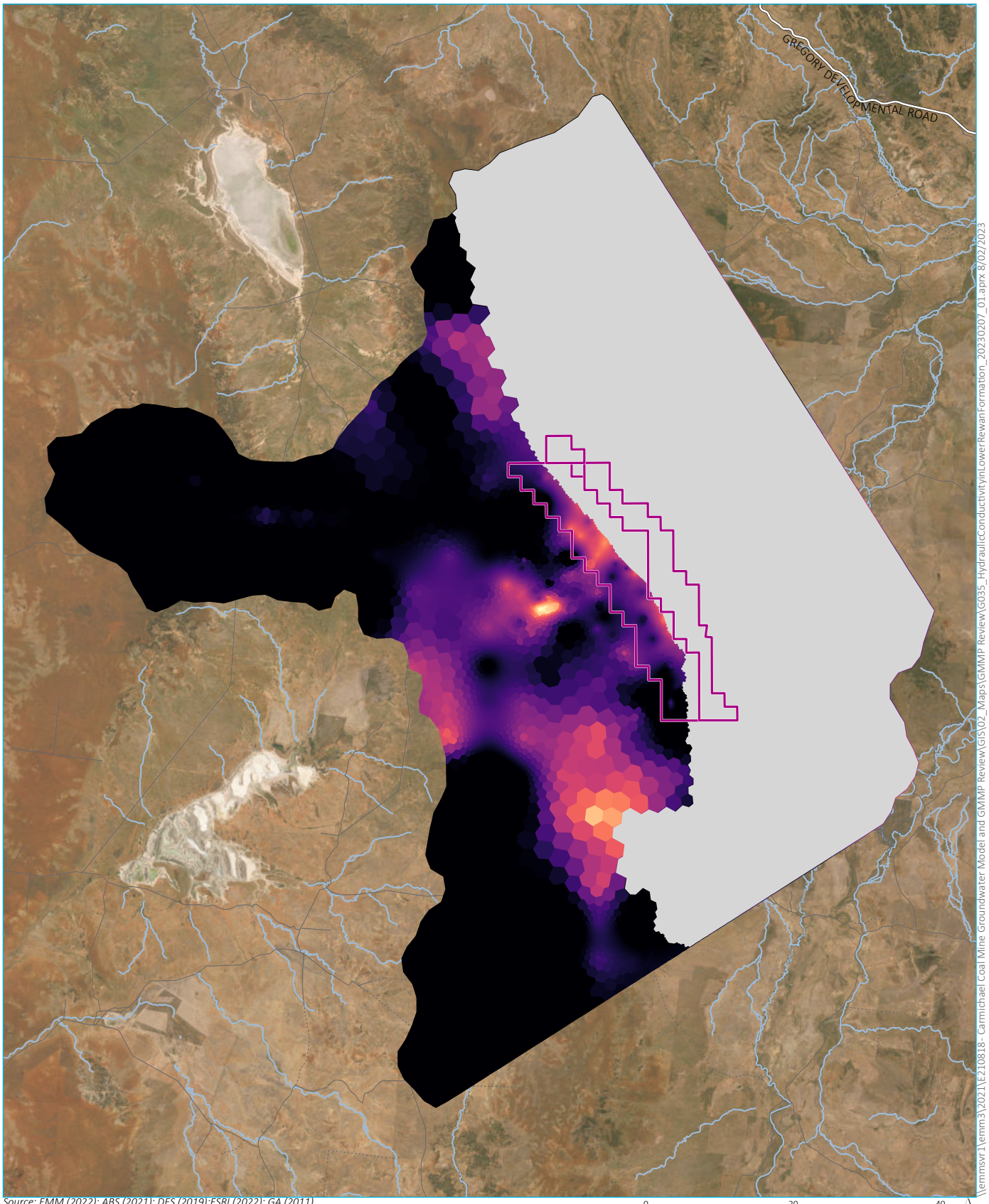

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Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Inactive area
- Major road
- Minor road
- Vehicular track

Log of hydraulic conductivity (m/d)

-17

-12

DRAFT

Base realisation modelled vertical hydraulic conductivity in lower Rewan Formation

Carmichael Coal Mine
GMMP Review
Figure 4.7

EMM
creating opportunities

c Layers 10 and 13: Permian coal seams

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 uniform distribution, with peak around 1-2 m/day. The D seam is simulated with a much lower hydraulic conductivity, with the history-matching process pushing values towards the lower end of conceptual bounds, 1 x 10^{-2} m/day.

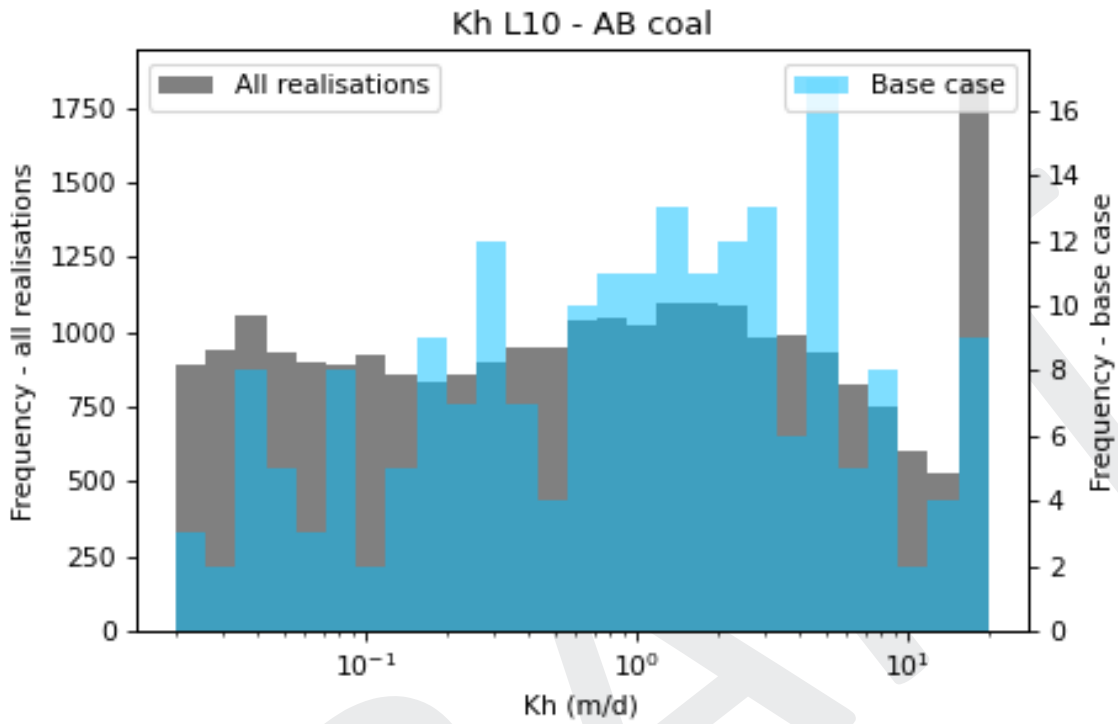

Figure 4.8 Kh pilot point parameter frequency distribution for AB Coal across base realisation and full ensemble of adopted realisations

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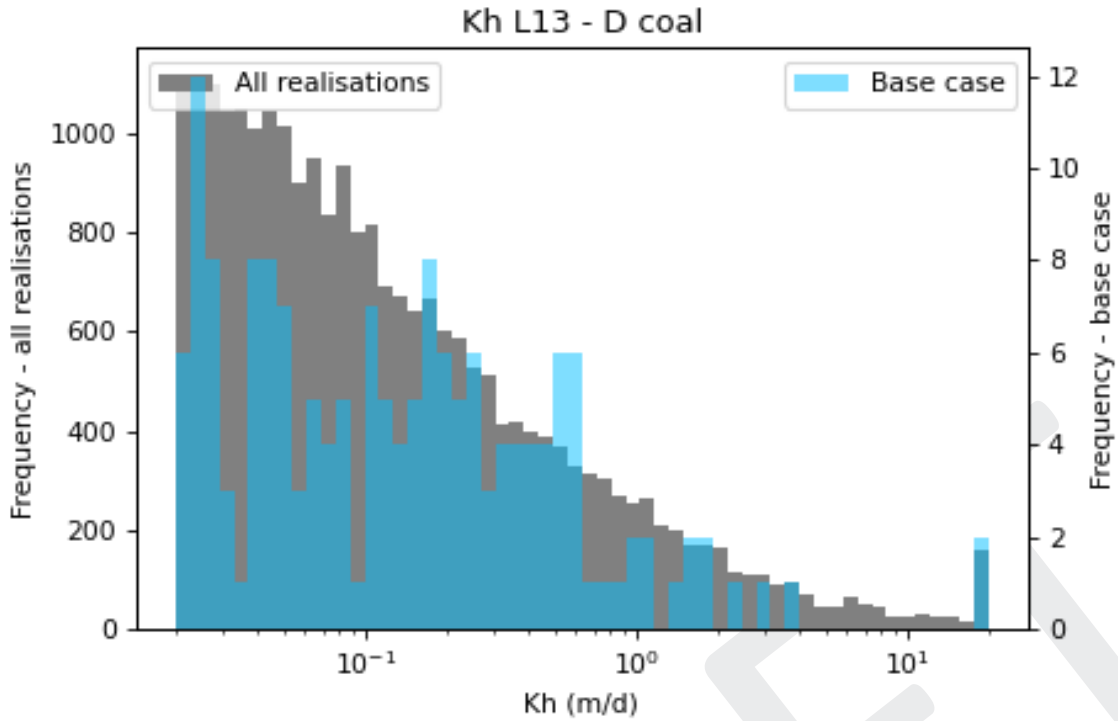

Figure 4.9 Kh pilot point parameter frequency distribution for D Coal across base realisation and full ensemble of adopted realisations

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 HSUs, lower hydraulic conductivity is simulated north of the Carmichael River for both coal seam layers.

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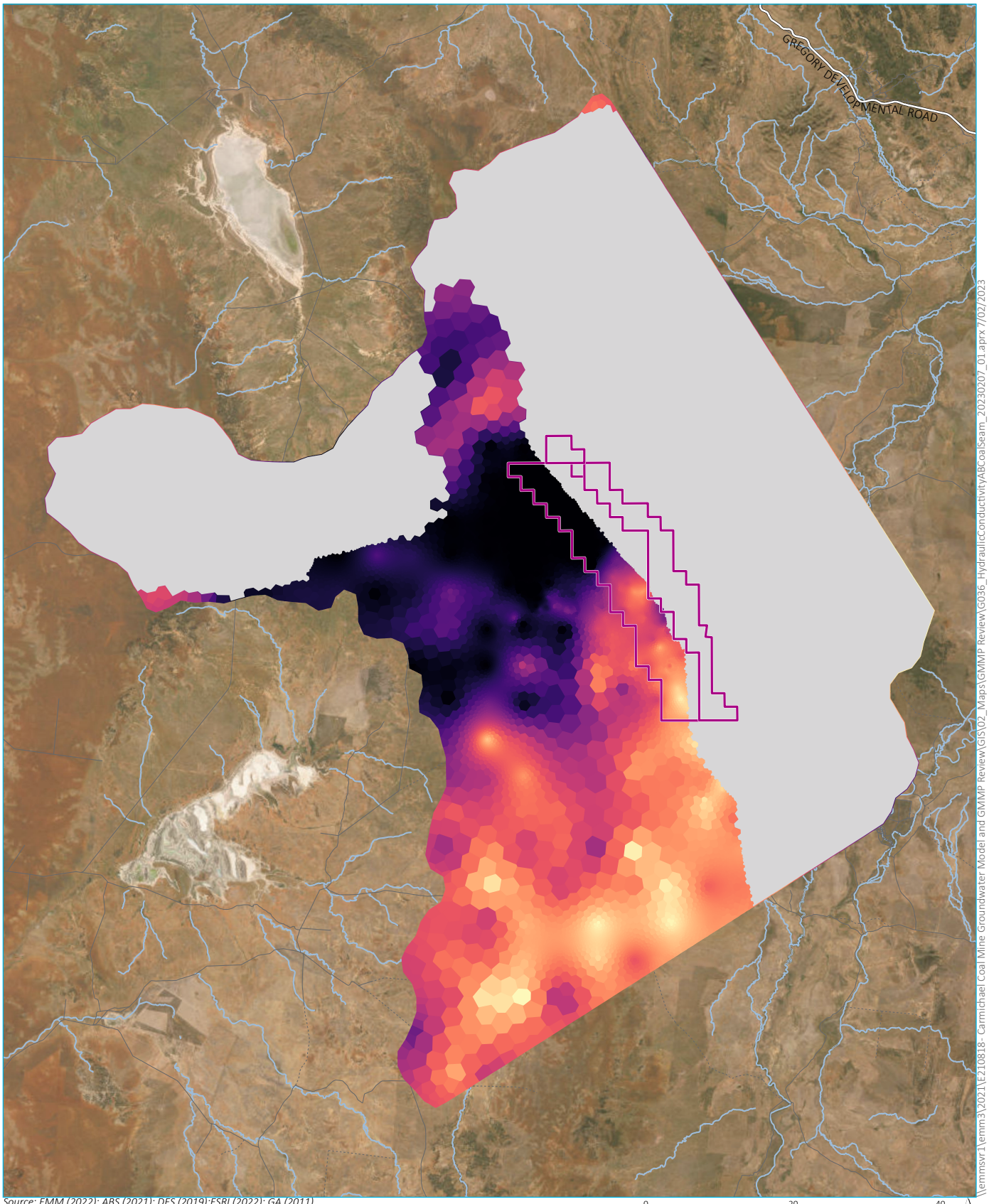

Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Inactive area
- Major road
- Minor road
- Vehicular track

Log of hydraulic conductivity (m/d)

-3.9

3.0

DRAFT

Base realisation modelled horizontal hydraulic conductivity in AB Coal seam

Carmichael Coal Mine
GMMP Review
Figure 4.10

EMM
creating opportunities

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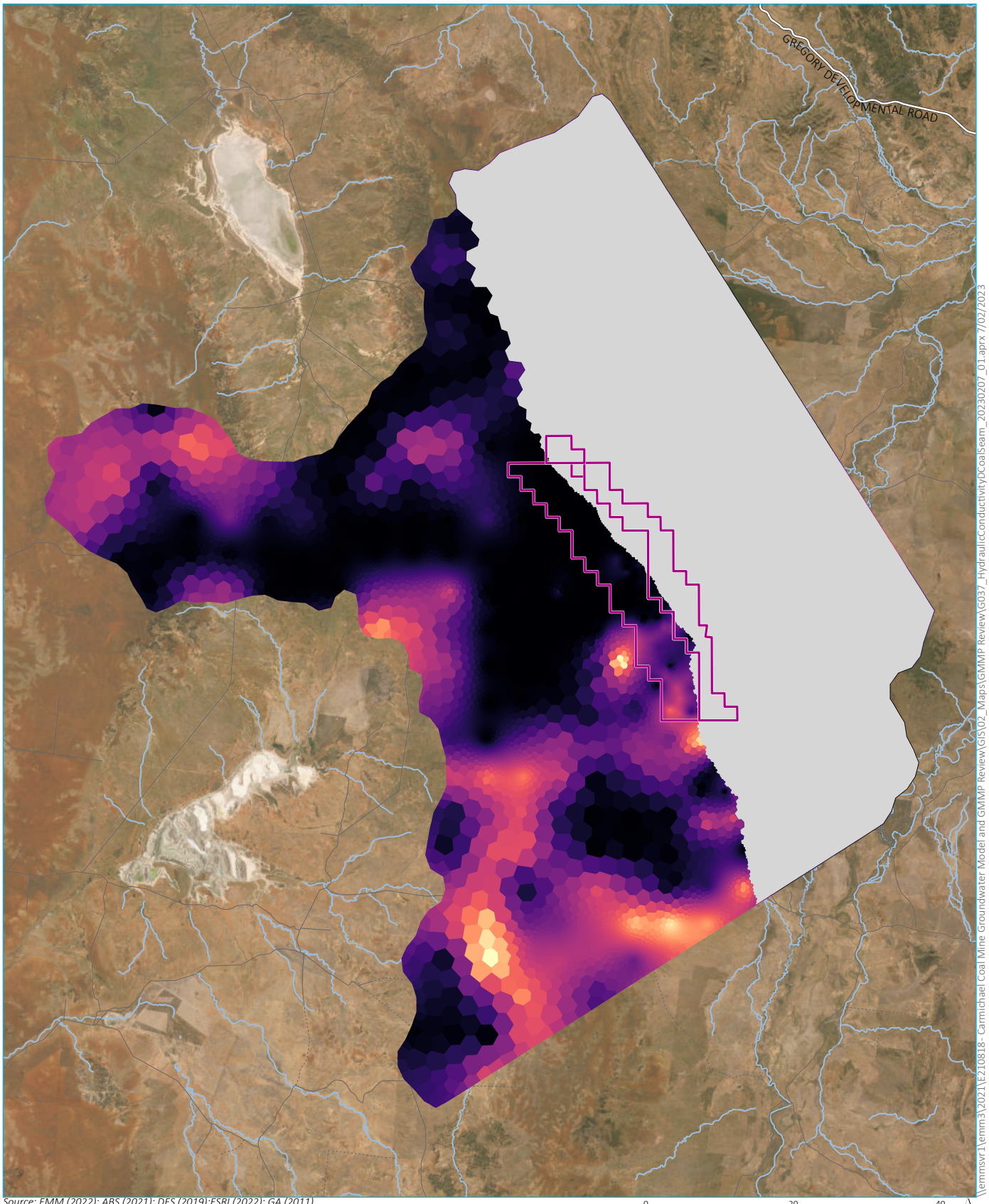

Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Inactive area
- Major road
- Minor road
- Vehicular track

Log of hydraulic conductivity (m/d)

-3.9

1.4

DRAFT

Base realisation modelled horizontal hydraulic conductivity in D Coal seam

Carmichael Coal Mine
GMMP Review
Figure 4.11

EMM
creating opportunities

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G037_HydraulicConductivityDCoalSeam_20230207_01.aprx 7/02/2023

d Other model parameters

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

4.2 Performance

4.2.1 Statistical performance

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

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 base case realisation

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.

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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%
90th percentile	13.0%	3.8%	8.2%
Median	12.1%	3.3%	7.5%
10th percentile	11.4%	2.9%	7.0%
Minimum	10.5%	2.5%	6.3%

In order to ensure suitable history-matching performance for the uncertainty ensemble, realisations were filtered with the following cut-off maximum accepted values:

- initial hydraulic head SRMS: 12.5%
- transient head-change SRMS: 3.5%
- 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 initial hydraulic head, grouped by HSU, is presented in Figure 4.12. The data show minimal bias, are correlated well across the dataset, and are generally clustered close to a 1:1 line of perfect fit. There are a few measured data points that are over- or underestimated by the model by 10 m or more, leading to the initial hydraulic head SRMS being over 10%. Despite this, the overall fit to measured data indicates a generally good match to regional groundwater levels and flow directions across multiple HSUs.

A scatter plot of modelled against measured initial hydraulic head for the base case and adopted ensemble of realisations is presented in Figure 4.13. The plot shows all data points for the base realisation in blue, and the datapoints for the full ensemble of adopted realisations in semi-transparent grey. The Gaussian distribution of parameter values leads to a range of simulated values for each measurement, within acceptable statistical metrics (as discussed above).

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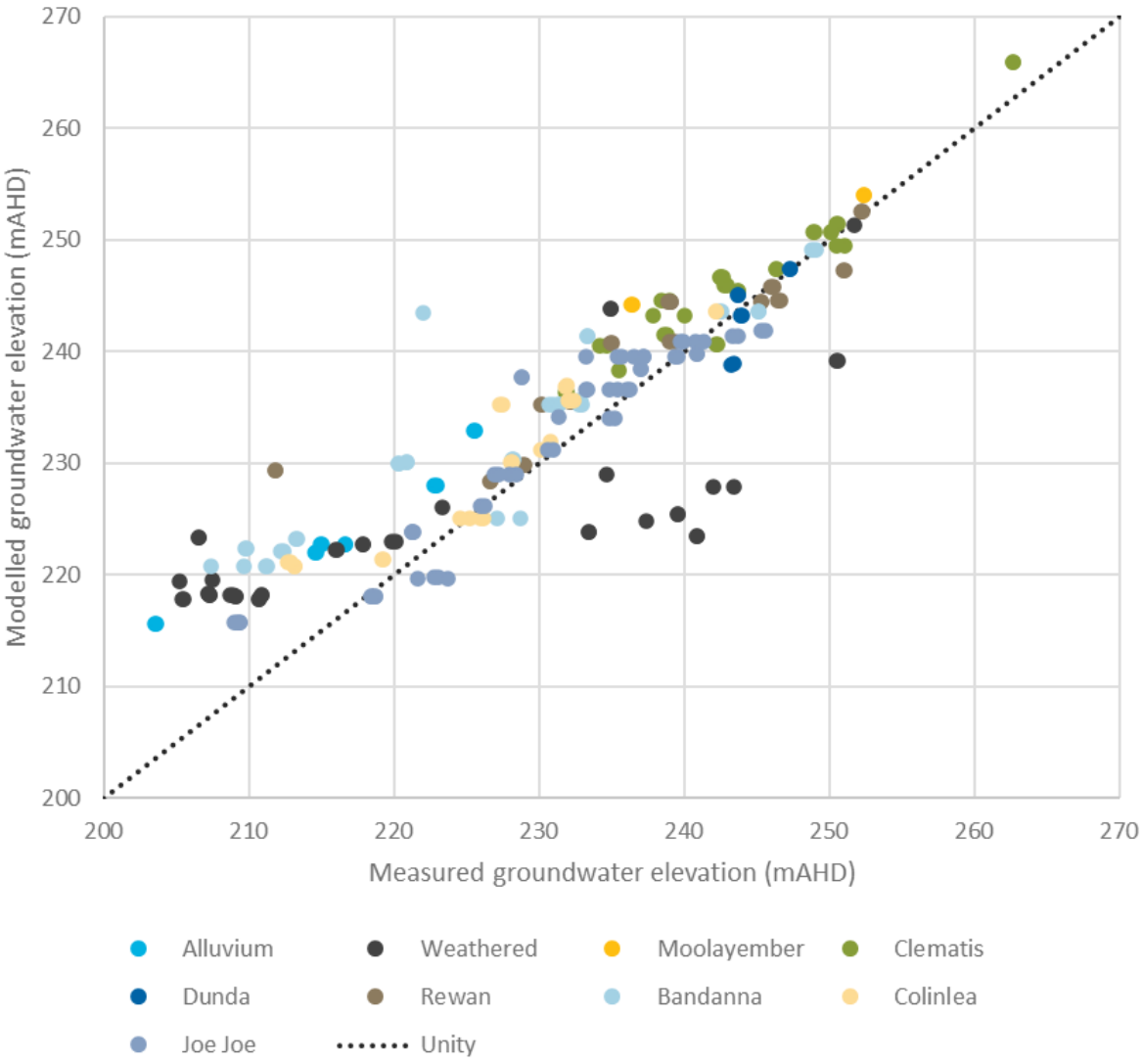


Figure 4.12 Modelled vs measured scatter plot of initial hydraulic head measurements for base realisation grouped by HSU

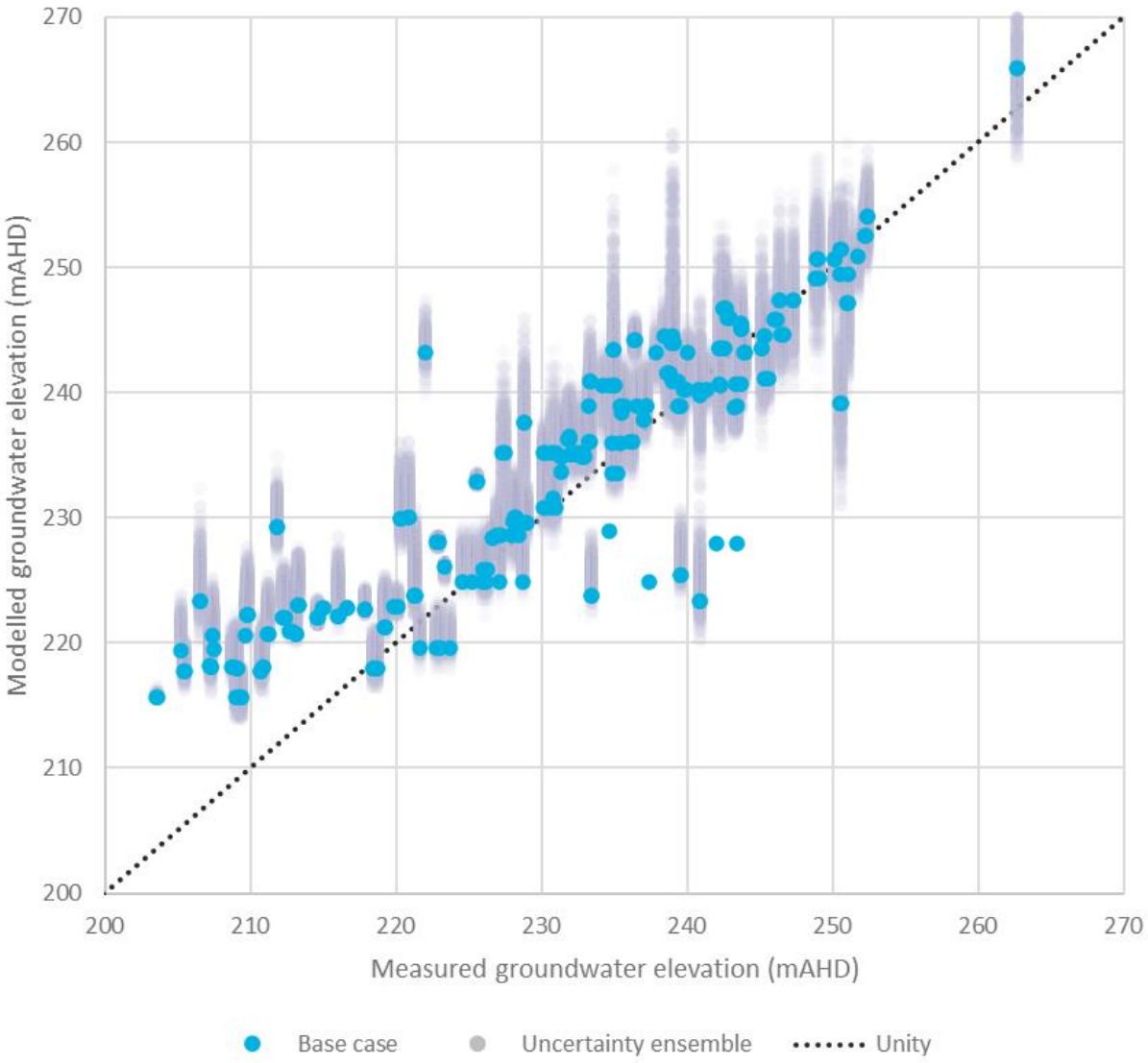
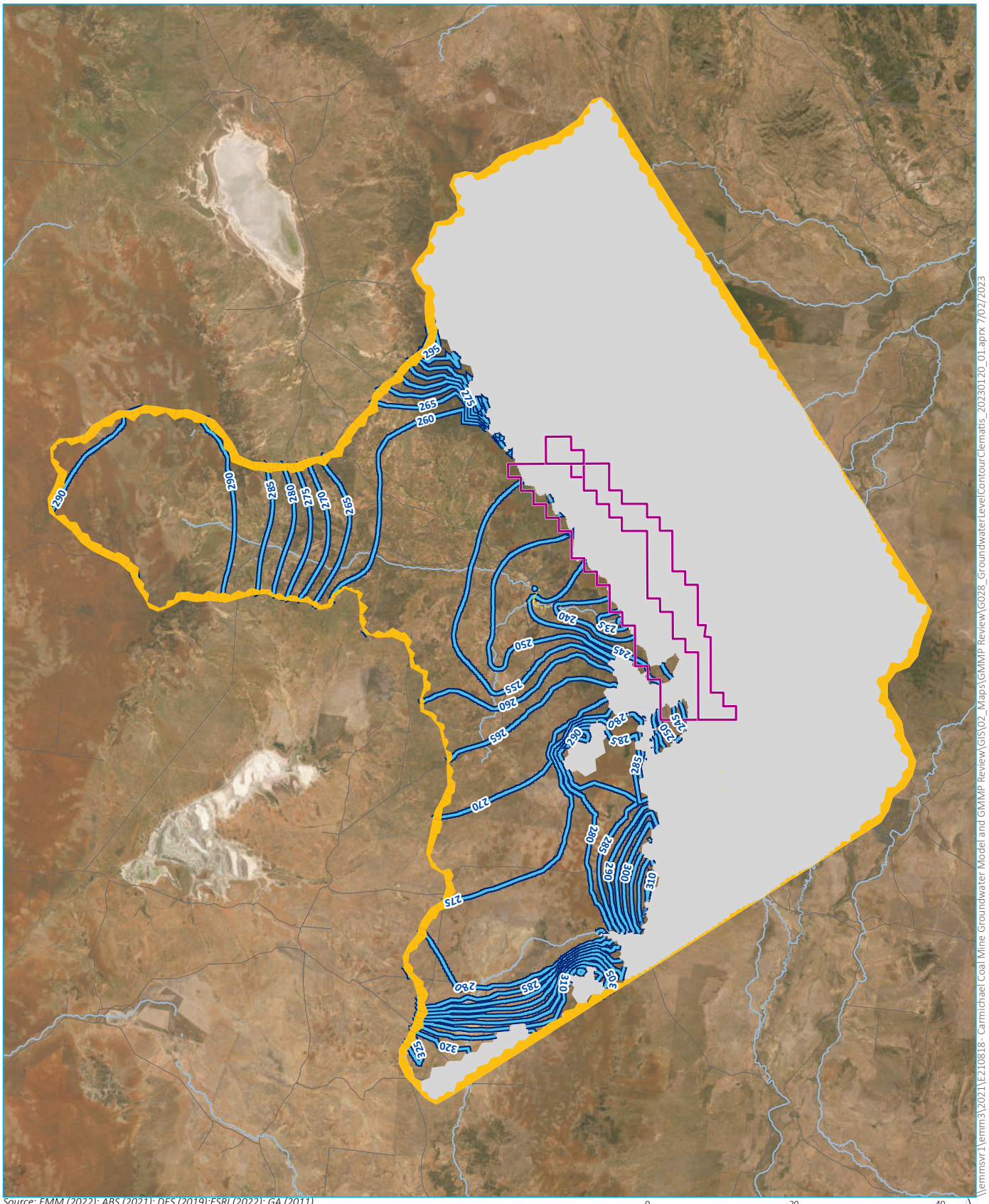


Figure 4.13 Modelled vs measured scatter plot of initial hydraulic head measurements for base realisation and full ensemble of adopted realisations

ii Modelled groundwater contours

Modelled steady state groundwater contours for the Clematis Sandstone, AB Coal seam, and D Coal seam are presented in Figure 4.14 to Figure 4.16 respectively. Groundwater is simulated to generally flow from west to east, with discharge from the HSUs at the subcrop line near the Carmichael River. Influence of the river is more apparent in the Clematis Sandstone than the deeper coal units, suggesting discharge to surface as baseflow. The modelled hydraulic low in the coal layers is north of the Carmichael River, below 225 mAHD. Measured groundwater levels in the weathered profile east of the subcrop suggest eastward flow of groundwater from the Permian units to the weathering zone.



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Model spring cells
- Model domain boundary
- Inactive area
- Modelled groundwater level (mAHD)
- Major watercourse
- Major road

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Modelled steady-state groundwater level contours in Clematis Sandstone

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GMMP Review
Figure 4.14

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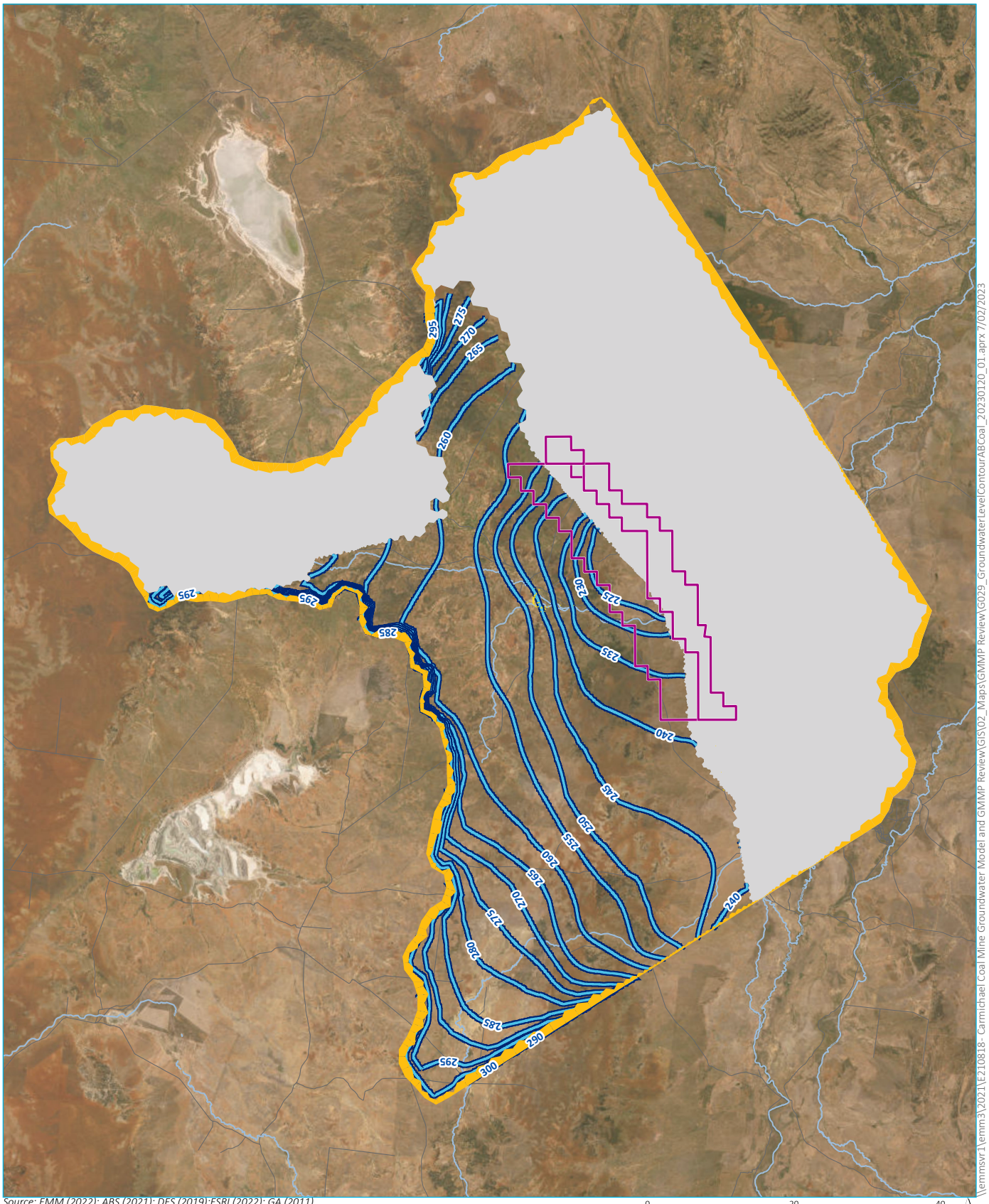

Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Model spring cells
- Model domain boundary
- Inactive area
- Modelled groundwater level (mAHD)
- Major watercourse
- Major road

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Modelled steady-state groundwater level contours in AB Coal

Carmichael Coal Mine
GMMP Review
Figure 4.15

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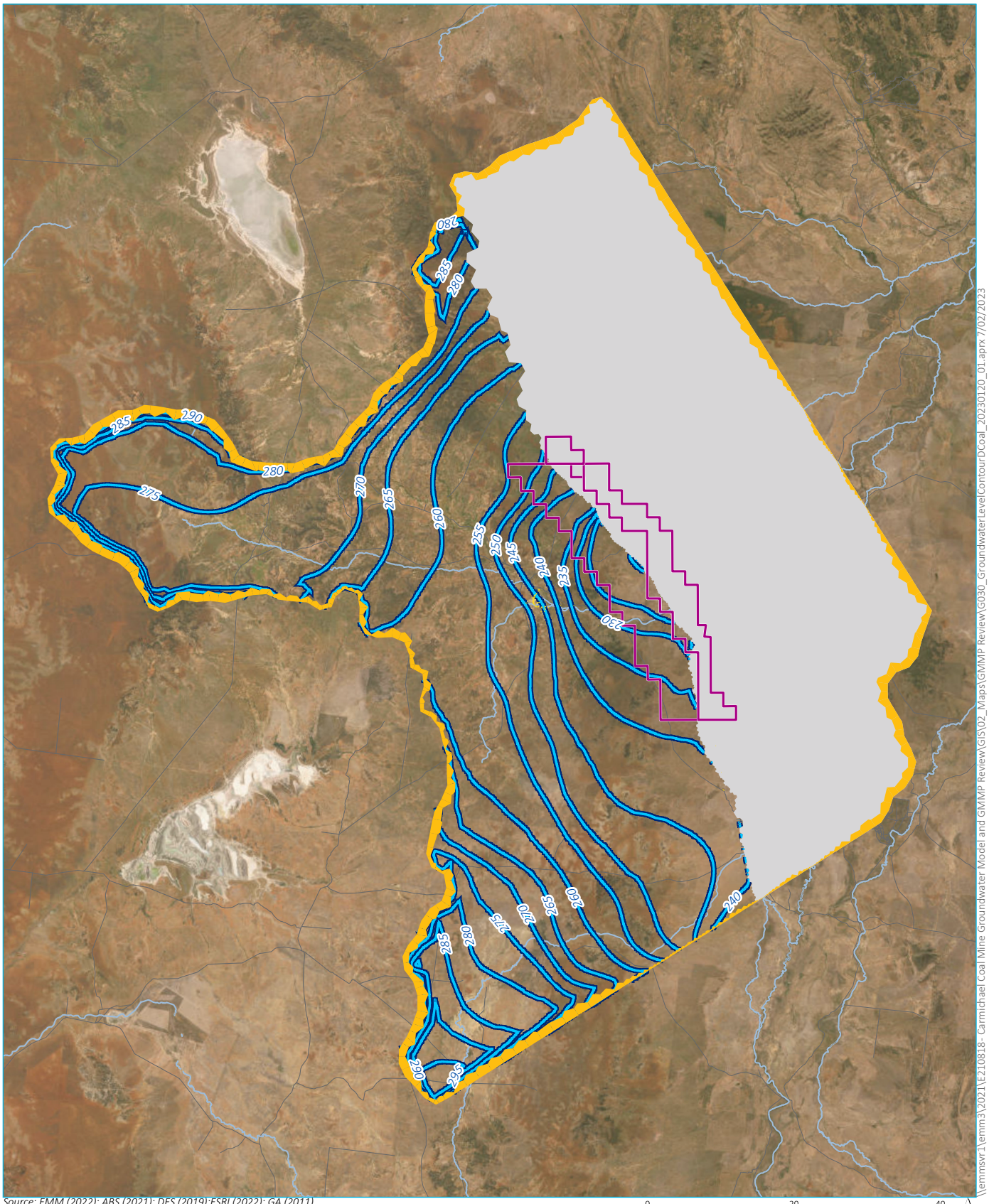
\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G029_GroundwaterLevelContourABCoal_20230120_01.aprx 7/02/2023



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 20 40 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Model spring cells
- Model domain boundary
- Inactive area
- Modelled groundwater level (mAHD)
- Major watercourse
- Major road

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Modelled steady-state groundwater level contours in D Coal

Carmichael Coal Mine
GMMP Review
Figure 4.16

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4.2.3 Drawdown

A scatter plot of modelled against measured head-change for the transient history-match dataset, grouped by HSU, is presented in Figure 4.17, with semi-transparency used due to the volume of data. The majority of data with head-change greater than 5 m are in the Bandanna and Colinlea formations; the model generally matches the head-change trend but with some mismatch greater than 20 m. The bulk of head-change data are between -5 and 5 m, of which the model matches drawdown better than climate-associated mounding. The large number of data points with small residuals leads to the low head-change SRMS below 5%.

A scatter plot of modelled against measured head-change for the ensemble of adopted realisations is presented in Figure 4.18. Similar to the initial hydraulic head scatter plot (Figure 4.13), though with a more pronounced impact of changing parameters on resultant match to measurements. This is reflected in Table 4.2, where the head-change SRMS values exhibit greater proportional spread than head SRMS values.

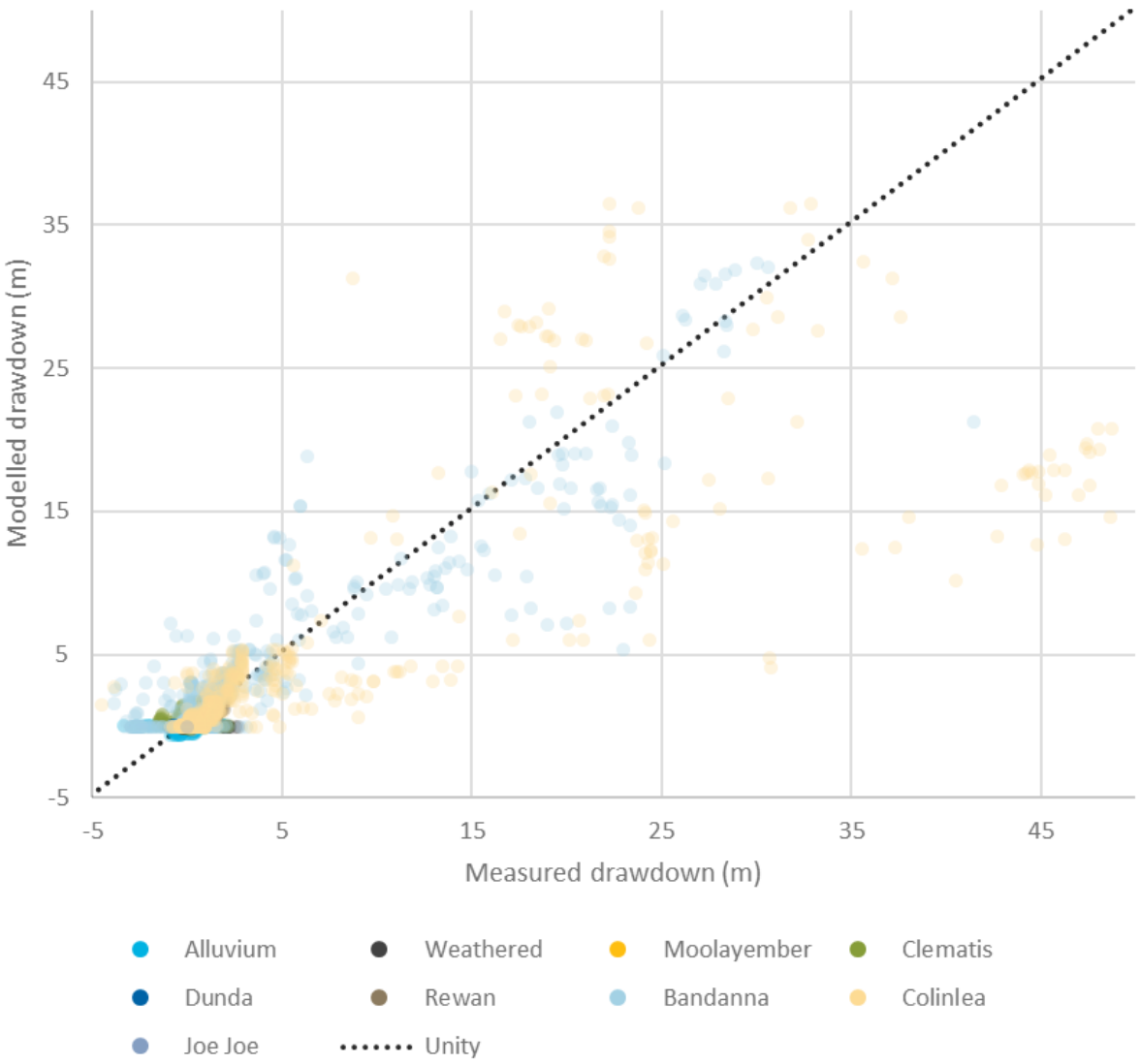

Figure 4.17 Modelled vs measured scatter plot of head-change for base realisation grouped by HSU

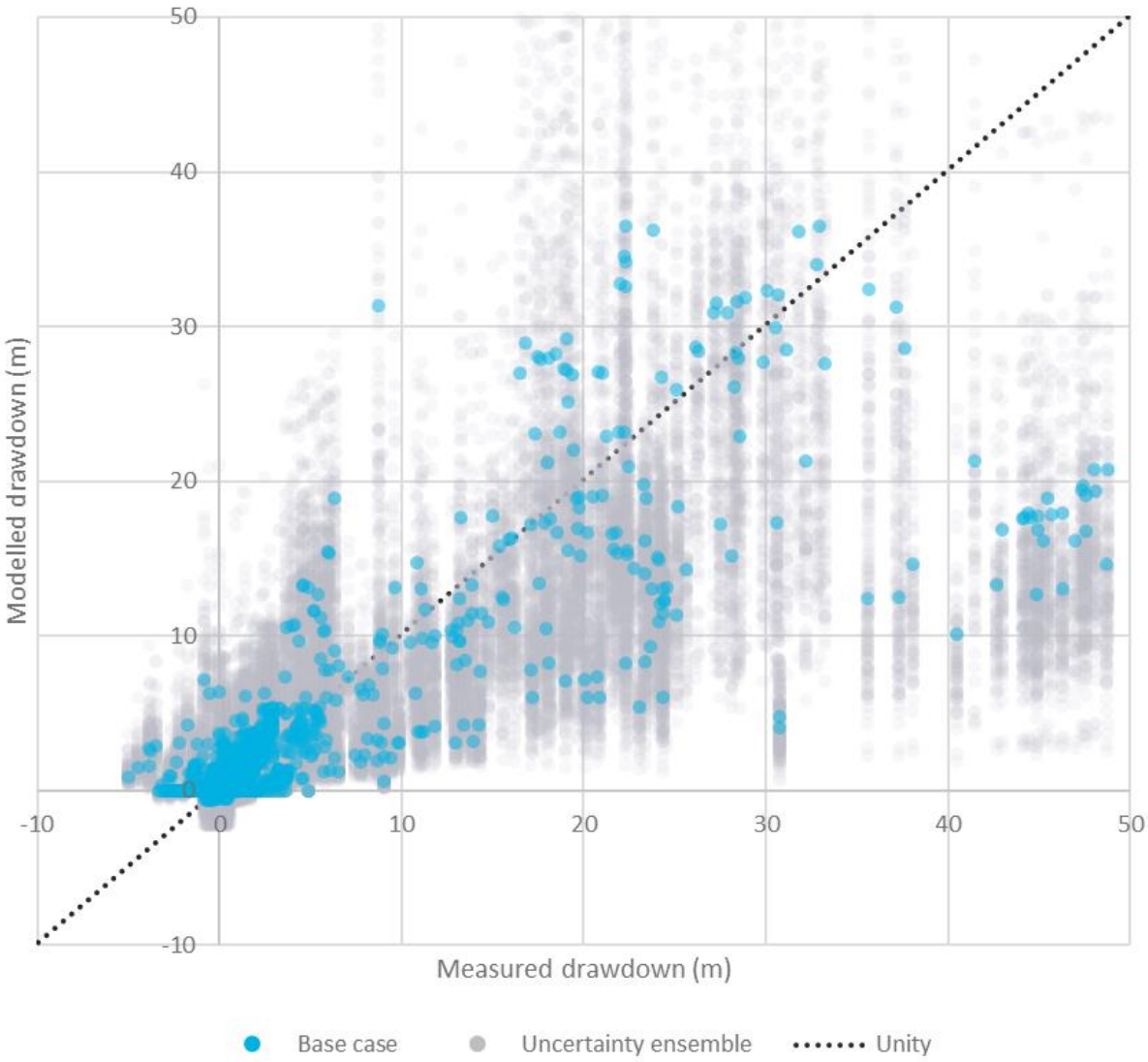

Figure 4.18 Modelled vs measured scatter plot of head change for base realisation and full ensemble of adopted realisations

4.2.4 Modelled hydrographs

Selected hydrographs showing modelled and measured hydraulic head are presented in Figure 4.19, with the full set of history-matching hydrographs presented in Appendix C. The chosen bores show variability in measured head-change from both climatic and mining stresses, and the modelled hydrographs (presented for both the base realisation and full ensemble of adopted realisations) show the variability in modelled head and head-change. As discussed above, the model was history-matched against initial hydraulic head and transient head-change, with separate target groups using by PESTPP-IES. This is shown in the hydrograph for C007P2 where, despite struggling to match absolute groundwater elevations, the uncertainty ensemble covers the range of measured transient head-change well.

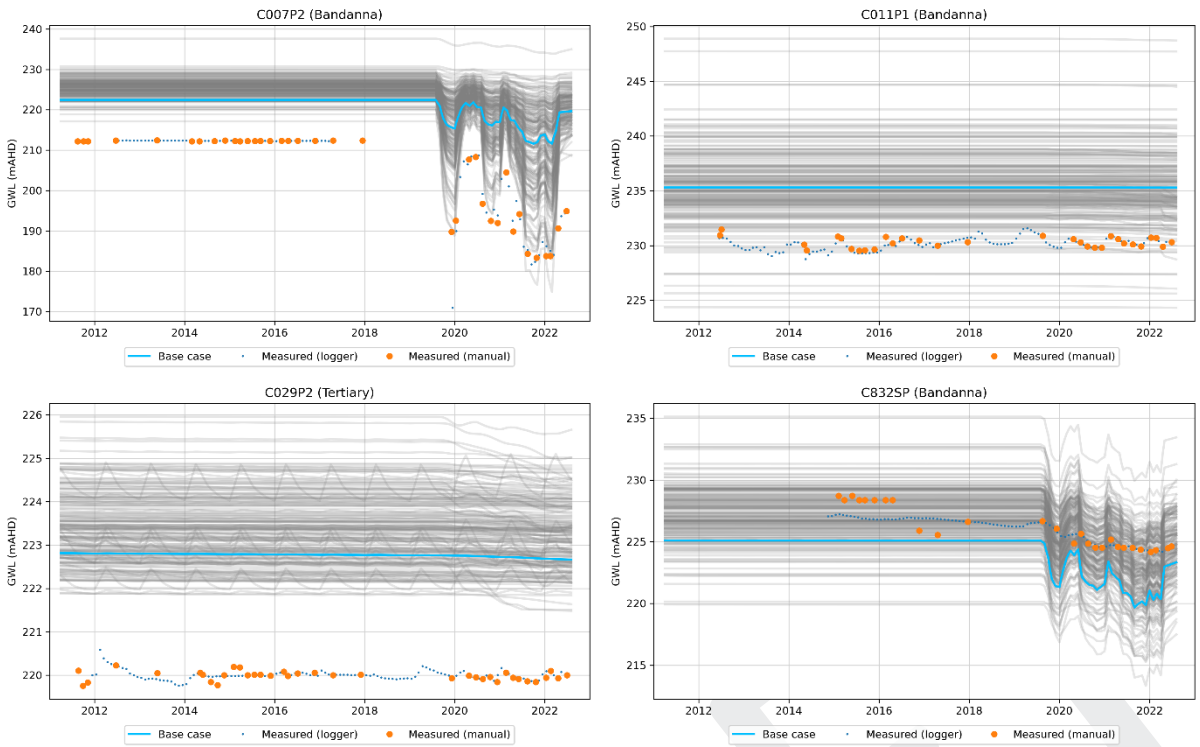

Figure 4.19 Selected history-matching hydrographs

4.2.5 Surface water – groundwater interaction

The Carmichael River is conceptualised to be a losing stream in the wet season and, along part of its length, a gaining stream in the dry season. This is reflected in river boundary condition design (Section 3.5.2), with a depth of saturation during the wet season and no saturation during the dry season. Figures showing modelled river boundary condition flux are presented for the wet and dry seasons in Figure 4.20 and Figure 4.21 respectively, with model cells coloured by flow direction (baseflow or seepage). During the wet season, seepage to groundwater is simulated across much of the length of the Carmichael River, with some areas of net modelled baseflow near the DSC. During the dry season, the area simulating baseflow is largely unchanged. The location and perennial nature of the modelled baseflow appears to be at least partially supported by discharging spring water.

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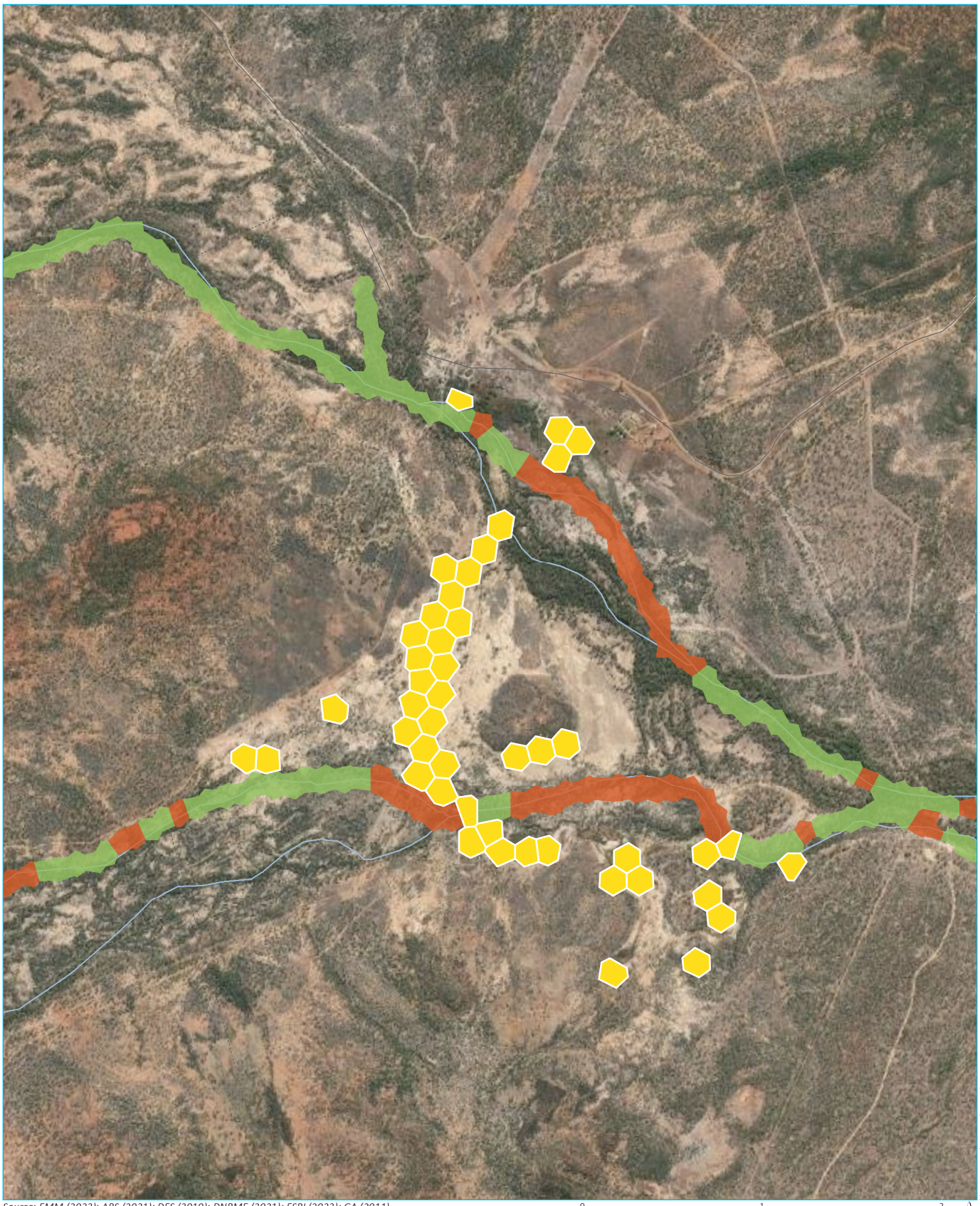

Source: EMM (2022); ABS (2021); DES (2019); DNRME (2021); ESRI (2022); GA (2011)

0 1 2 km

GDA 1994 MGA Zone 55

N

\\emmsvr1\emm3\2021\E210818 - Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G031_SeepageRegionsWetSeason_20230207_01.mxd 7/02/2023

KEY

- Major watercourse
- Modelled spring cell
- Baseflow
- Seepage

Modelled baseflow and seepage regions - wet season

Carmichael Coal Mine
GMMP Review
Figure 4.20

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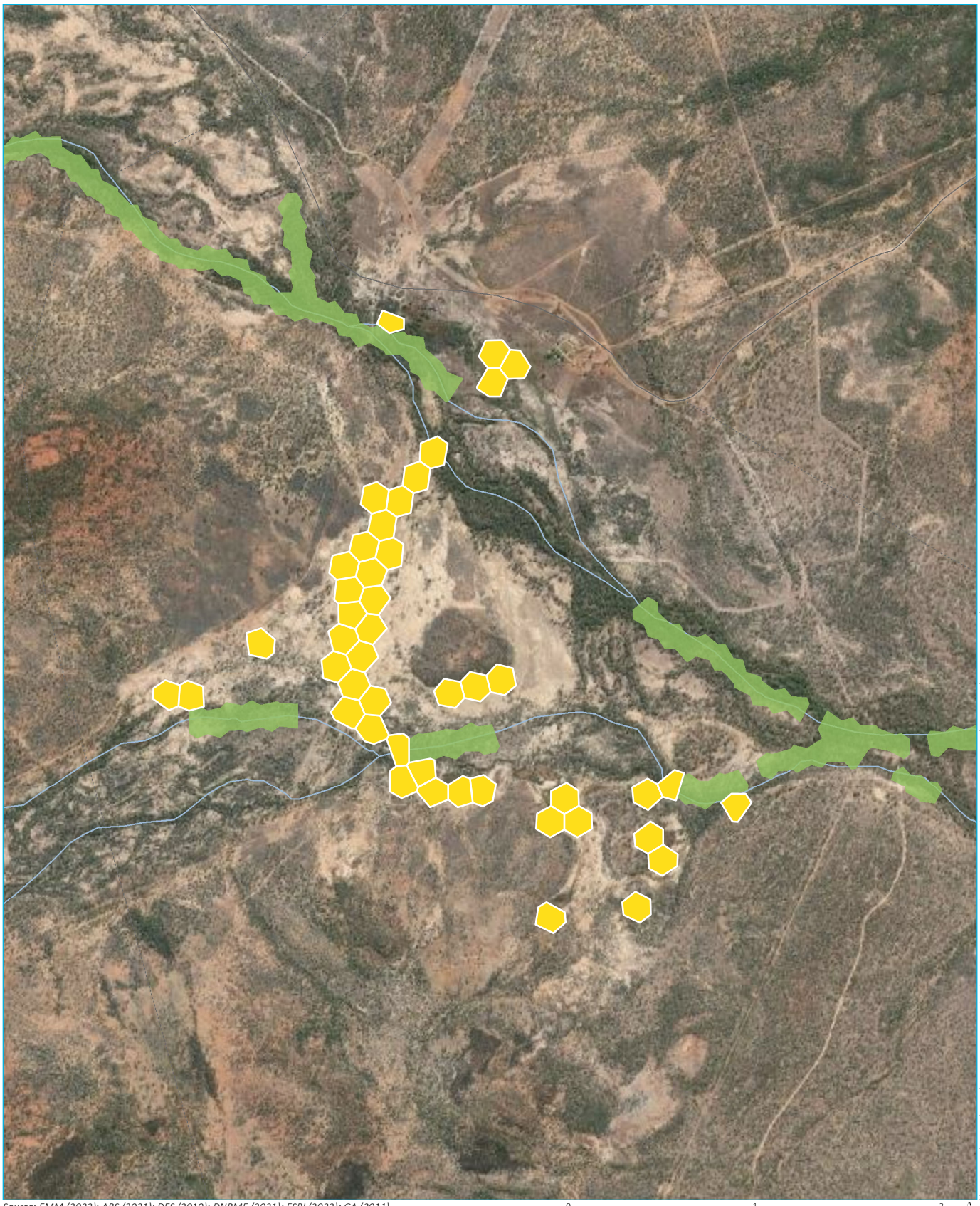

Source: EMM (2022); ABS (2021); DES (2019); DNRME (2021); ESRI (2022); GA (2011)

0 1 2 km

GDA 1994 MGA Zone 55

N

KEY

- Major watercourse
- Modelled spring cell
- Baseflow

Modelled baseflow and seepage regions - dry season

Carmichael Coal Mine
GMMP Review
Figure 4.21

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\\emmsvr1\emm3\2021\E210818 - Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G032_SeepageRegionsDrySeason_20230207_01.mxd 7/02/2023

4.2.6 Spring flow

Modelled spring flows for the Joshua Spring and other Doongmabulla Springs are compared with estimated values in Table 4.3, for the base case and full ensemble of adopted realisations. PESTPP-IES used modelled flux at these spring locations as a history-matching target group (refer Section 4.1.1), and across the ensemble of realisations returned a range of modelled fluxes surrounding the target estimates. Spring flux was not used to filter acceptable model realisations, as the estimated fluxes are less certain than groundwater level measurements.

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
90th percentile	1,198	894
Median	802	534
10th percentile	527	295
Minimum	146	143

4.3 Water balance

The modelled steady state water balance is presented in Table 4.4, with a time series chart for the history-matching period in Figure 4.22. The modelled water balance is dominated by regional throughflow, with substantial river leakage during the wet season. Water flux via evapotranspiration increases in response to river leakage, tapering off during subsequent dry season stress periods. The modelled mass balance error is low, suggesting good numerical performance.

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**	
Water balance error	**0.01%**	

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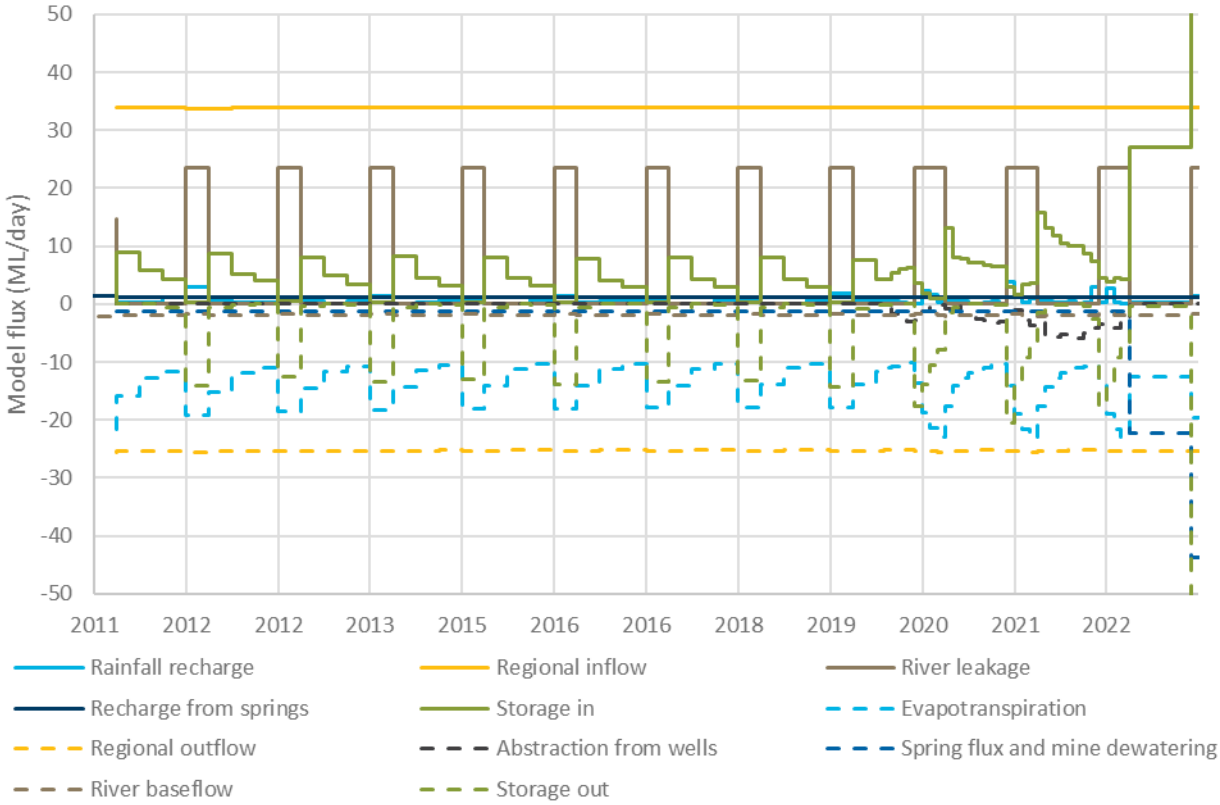

Figure 4.22 Modelled water balance for the history-matching period

4.4 Comparison with SEIS model

4.4.1 Model parameters

Comparison of model hydraulic parameters as reported in the SEIS (GHD 2013a) with history-matched parameter values in the updated model is presented in Table 4.5. The SEIS groundwater model used homogeneous parameter values within each HSU, whereas the updated model incorporates a highly parameterised Gaussian log-distributed approach with an ensemble of parameter realisations. Direct comparison is therefore not possible; comparisons in Table 4.5 use the most frequent modelled values per HSU from the updated model (refer Appendix B) with no comparison of numerical or spatial distributions.

The SEIS and updated groundwater model have substantially different hydraulic properties for many of the HSUs, by up to 4 orders of magnitude. In general, the updated model has lower hydraulic conductivity and specific yield in shallower layers, and higher hydraulic conductivity and specific yield in deeper layers. Changes to modelled hydraulic properties follow the changes to model design and history-matching approach.

Table 4.5 Comparison of updated and SEIS modelled hydraulic properties

HSU	Hydraulic conductivity	Specific storage	Specific yield
Quaternary alluvium	Similar between models	N/A	Variable, updated model ranges from similar to SEIS to 4 orders of magnitude lower
Weathering zone	Not simulated in SEIS		

Table 4.5 Comparison of updated and SEIS modelled hydraulic properties

HSU	Hydraulic conductivity	Specific storage	Specific yield
Tertiary and non-alluvial Quaternary deposits	Slightly lower in updated model	2 orders of magnitude lower in updated model	2 orders of magnitude lower in updated model
Moolayember Formation	2 orders of magnitude lower in updated model	Slightly higher in updated model	2 orders of magnitude lower in updated model
Clematis Sandstone/Warang Sandstone	Slightly lower in updated model	Slightly higher in updated model	2 orders of magnitude lower in updated model
Dunda Beds	3 orders of magnitude lower in updated model	2 orders of magnitude lower in updated model	2 orders of magnitude lower in updated model
Rewan Formation	Similar between models, though updated model includes reducing conductivity in lower profile	1 order of magnitude higher in updated model	2 orders of magnitude lower in updated model
Bandanna Formation	Slightly higher in updated model	Similar average between models, wide range for updated model	1 order of magnitude higher in updated model
Bandanna Formation (AB Seam coal)	3 orders of magnitude higher in updated model	2 orders of magnitude lower in updated model	1 order of magnitude higher in updated model
Bandanna Formation	2 orders of magnitude higher in updated model	1 order of magnitude lower in updated model	1 order of magnitude higher in updated model
Colinlea Sandstone	1-2 orders of magnitude higher in updated model	1 order of magnitude lower in updated model	1 order of magnitude higher in updated model
Colinlea Sandstone (D Seam coal)	1-2 orders of magnitude higher in updated model	2 orders of magnitude lower in updated model	1 order of magnitude higher in updated model
Colinlea Sandstone	3-4 orders of magnitude higher in updated model	Similar between models	1 order of magnitude higher in updated model
Joe Joe Group	3-4 orders of magnitude higher in updated model	Similar between models	2 orders of magnitude lower in updated model

4.4.2 History-matching performance

The SEIS groundwater model was history-matched to steady state hydraulic heads only from 88 bores, with a reported SRMS of 4.5%. On face value, this may appear a better performance than the updated groundwater model, which reports SRMS against initial hydraulic head measurements from 239 bores of 10.9%. However, this statistic, taken without context, is misleading, as the SRMS model had a mean absolute residual of 7.94 m, and the updated model mean absolute residual is 5.49 m. Therefore, the history-matching performance against initial groundwater levels is better in the updated model. Additionally, the transient head-change targets employed in the updated model allow for history-matching of storage parameters, which could not be done in the SEIS model which employed steady state history-matching only.

4.4.3 Water balance

The net modelled water balance fluxes for the SEIS and updated groundwater models are presented in Table 4.6. The most significant difference with regard to the hydrogeological conceptual model is that the SEIS model simulates the Carmichael River to be a net baseflow feature (wet/long term average stress period) whereas the

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updated model simulates net leakage, which is more consistent with the conceptualisation (EMM 2022a). Other differences, such as evapotranspiration, are associated with this different modelled river flux.

Table 4.6 Pre-development water balance comparison

Component	SEIS net flux (ML/d)	Updated model net flux (ML/d)	Comparison
Regional throughflow	3.21	8.23	SEIS model has larger individual fluxes (>40 ML/d) but smaller net inflow
Rainfall-derived recharge	2.53	0.69	Significant reduction in modelled recharge in updated model
Evapotranspiration	-4.00	-21.72	Significant increase in modelled evapotranspiration in updated model
River baseflow/leakage	-1.62	12.81	SEIS model simulates net baseflow, updated model simulates net leakage, which is consistent with the updated conceptualisation (note reporting data from long-term steady state stress period with 'wet' conditions)
Spring discharge	N/A	0.02	Not specified for SEIS model
Storage	0	0	Steady state for both models

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5 Predictive modelling

5.1 Overview and approach

Three scenarios were defined for predictive modelling as follows:

1. Open cut only scenario. This scenario simulates the open cut pits only, with all underground mine workings excluded.

2. SEIS A scenario- This scenario uses the updated model but assumes the same fracturing properties (fracturing height and property multipliers) as the SEIS model (GHD 2013). This scenario simulates the full SEIS mine plan (i.e. both open cut and underground). Regarding the fracturing approach, this scenario assumes:

    a) a 150 m fracturing height above the mined coal seams

    b) an increase in hydraulic conductivity of 50x for the lower 75 m and 10x for the upper 75 m in all model cells within this assumed zone of fracturing.

3. SEIS B scenario- This scenario simulates the same mine plan as the SEIS using the updated model, however the representation of fracturing above longwall mining has been updated to include the following:

    a) Fracturing heights were estimated previously as part of the RFCRP, with numerical geomechanical modelling predicting fracturing 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 suggests fracturing to surface for 48% of the underground mine footprint. This scenario simulates a fracture height of 250 m up to the base of the Moolayember.

    b) Properties of the fractured zone above longwall panels use the ramp function as outlined in Section 3.5.5iii.

    c) The stress relief zone has been incorporated as a halo of increased permeability above and adjacent to the longwall panels, excluding the uppermost model layers which represent sediments with higher clay content (i.e. the alluvium, weathered zone and tertiary sediments). A maximum horizontal and vertical conductivity of 5 m/d was assumed with the ramp function applied.

The updated scenarios 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 those for the open cut only and SEIS B scenarios, which can be considered the 'bookends' of likely groundwater impacts. The project, at this stage, is proposing to assess the open cut only scenario as the planned operating scenario, with a commitment to update the groundwater model and develop an optimised underground mine plan prior to the commencement of underground mining, which is planned for 2037.

5.1.1 Assessing likelihood of drawdown

The maximum drawdown predicted for the Clematis Sandstone and the predicted likelihood of exceedance of the 0.2 m threshold set at spring locations are shown in Section 5.3.2i. At this stage, the likelihood of drawdown assessment (requiring an ensemble of predictions) has been completed only for the open cut only scenario (Scenario 1). The base case realisations for the SEIS A and SEIS B scenarios have been simulated to allow a comparison to the previous SEIS model (GHD 2013).

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To calculate the likelihood of a given drawdown a method was employed whereby, at each model cell, for each parameter realisation, the maximum modelled drawdown (irrespective of time) was calculated. Then, the proportion of realisations in which drawdown at a model cell exceeds a given value can be calculated.

The rationale for the percentile-based approach to presenting drawdown from 105 realisations is based on Table 2 of the IESC guidance note on uncertainty analysis (Middlemis and Peeters 2018). That emphasises 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 describing 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

The base case realisation modelled water balances for the three scenarios are shown in Figure 5.1 to Figure 5.3. Common to all scenarios, the water balance is dominated by groundwater being removed from the model (negative values) by mine dewatering, which includes a minor amount of water representing spring discharge. Mine dewatering is largely balanced by groundwater fluxes from storage. The peaks associated within mine dewatering and corresponding storage-in terms are dictated by the mine schedule and represent the commencement of new mining areas, based on the schedule shown in Table 3.4. Mine inflows and corresponding storage-in fluxes increase from the open cut only to the SEIS A scenario, and increase again to the SEIS B scenario, due to addition of the underground mine plan and assumptions associated with longwall mining effects on the overburden respectively.

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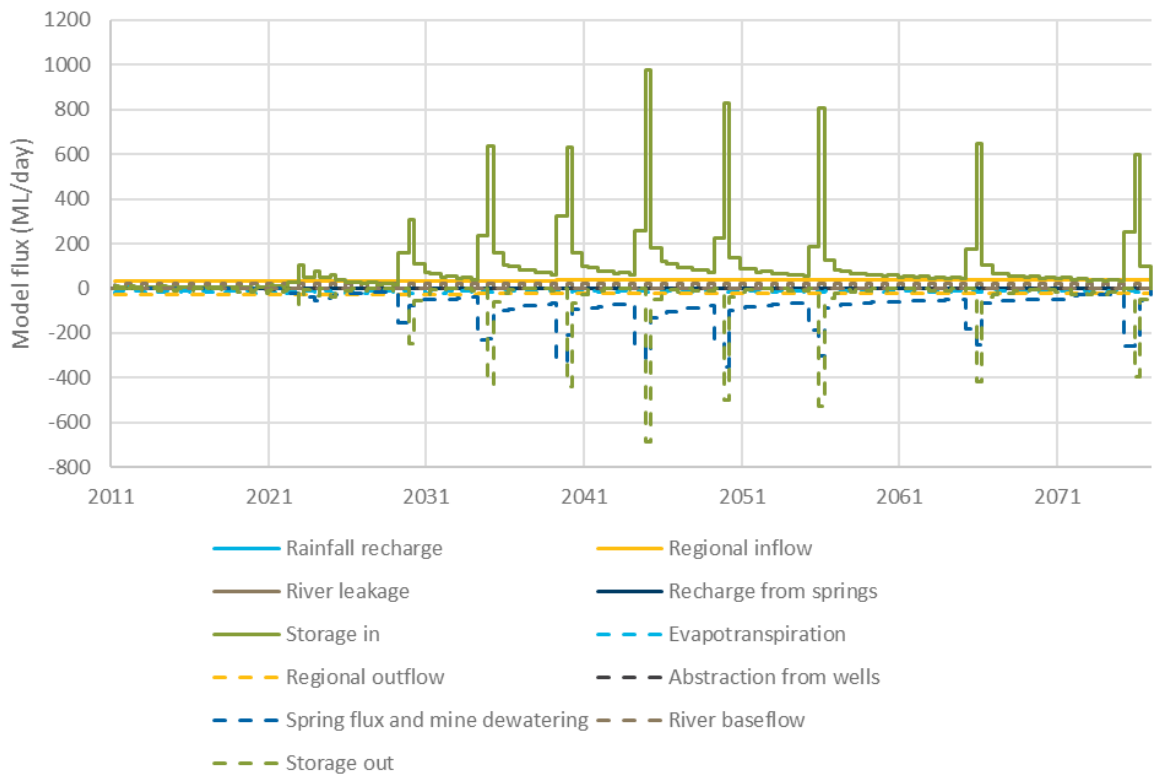

Figure 5.1 Open cut only modelled water balance

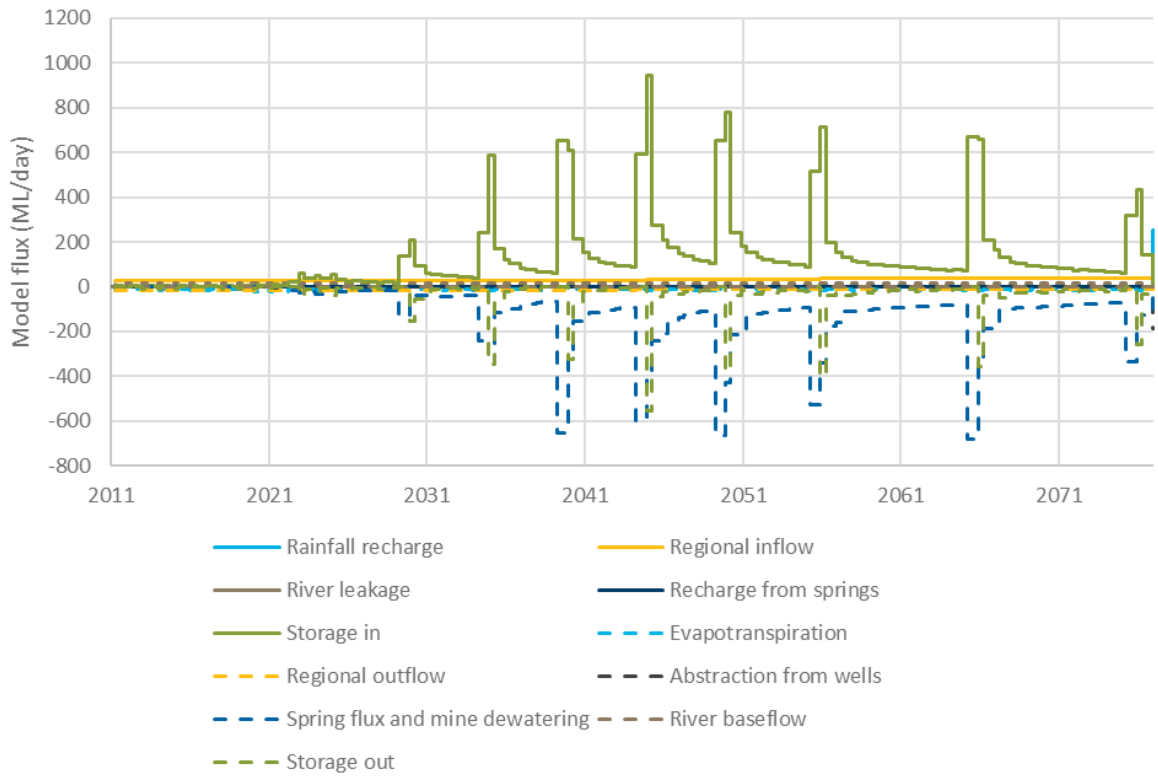

Figure 5.2 SEIS A modelled water balance

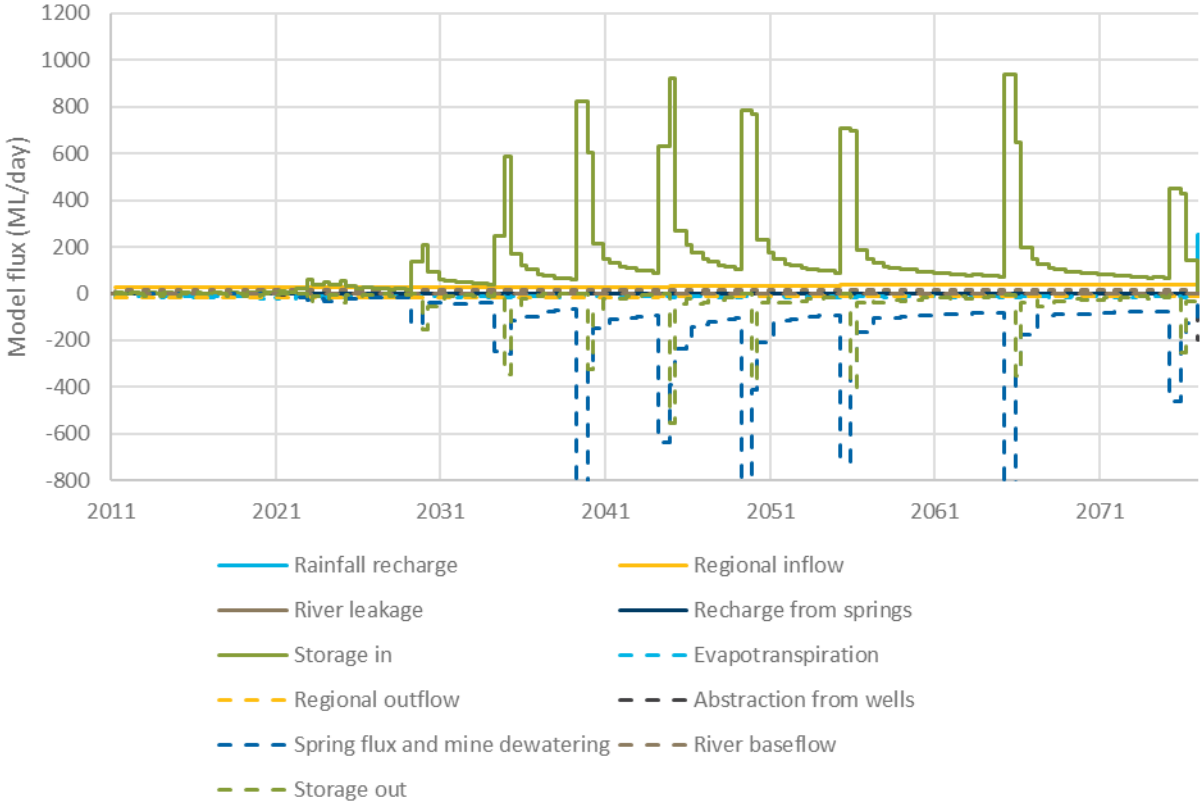

Figure 5.3 SEIS B modelled water balance

b Mine inflows

Base case realisation average modelled mine inflows over the life of operations are summarised in Table 5.2 to Table 5.4 for the three scenarios and Table 5.5 summarises the 2013 SEIS modelled mine inflows. The updated model simulates mine inflows far greater than the 2013 SEIS, largely due to the history-matching process resulting in larger hydraulic conductivity and storage values (refer to Table 4.5) for the Permian sediments. Modelled peak average inflows for the open cut, SEIS A and SEIS B scenarios were 134 ML/d, 237 ML/d and 239 ML/d respectively compared to a much smaller modelled peak of 26 ML/d for the 2013 SEIS model.

Due to the Gaussian distribution of property values and proportionally large mine area, changes in parameter values leading to increased/decreased simulated inflow in one area are typically balanced by changes to the opposite effect in other areas. As a result, there is greater variance between scenarios than across the ensemble of predictions for a given scenario, which gives a predicted range approximately ±20% from the base realisation.

Table 5.2 Predicted base realisation mine inflow (ML/day) for open cut only scenario

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	27.2	0	27.2

Table 5.2 Predicted base realisation mine inflow (ML/day) for open cut only scenario

Mine year	Open cut	Underground	Total
5	30.7	0	30.7
10	59.4	0	59.4
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
47	60.2	0	60.2

Table 5.3 Predicted base realisation mine inflow (ML/day) for SEIS A scenario

Mine year	Open cut	Underground	Total
1	0.4	-	0.4
2	0.8	-	0.8
3	3.1	-	3.1
4	27.2	-	27.2
5	30.7	-	30.7
10	59.4	-	59.4
15	113.6	11.9	125.5
20	121.6	86.9	208.6
25	134.3	102.7	237.0
30	108.6	98.3	206.9
35	78.5	56.0	134.5
47	60.2	83.8	144.0

Table 5.4 Predicted base realisation mine inflow (ML/day) for SEIS B scenario

Mine year	Open cut	Underground	Total
1	0.4	-	0.4
2	0.8	-	0.8
3	3.1	-	3.1
4	27.2	-	27.2

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Table 5.4 Predicted base realisation mine inflow (ML/day) for SEIS B scenario

Mine year	Open cut	Underground	Total
5	30.7	-	30.7
10	59.4	-	59.4
15	113.6	12.7	126.4
20	121.6	111.8	233.4
25	134.3	105.2	239.4
30	108.6	106.5	215.1
35	78.5	66.4	144.9
47	60.2	101.3	161.4

Table 5.5 Predicted mine inflow (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

5.3 Drawdown related effects

5.3.1 Overview

Drawdown analysis was undertaken for the base case realisation for all three scenarios and, additionally, for the full adopted ensemble of realisations for the open cut only scenario. Drawdown was calculated at every output time by subtracting the modelled hydraulic heads at each model cell for the given scenario from a null case (no mining) scenario. Drawdown analysis was completed over the combined duration of history-matching, mine operation and closure periods.

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5.3.2 Spatial groundwater responses

i Clematis Sandstone

Figure 5.4, Figure 5.5 and Figure 5.6 show the maximum modelled drawdown in the Clematis Sandstone (model layer 5), irrespective of time, for the open cut, SEIS A and SEIS B scenarios respectively. Referring to Figure 5.4, much of the drawdown is simulated in the southern area of the mine lease, emanating from open cut pits F and G. Referring to the 0.1 m drawdown contour, this extends to approximately 17 km west of the mining lease. The modelled drawdown response is caused by two main factors:

1. The updated geological model includes pockets of Clematis Sandstone further to the east compared to the sub-cropping implemented to the north. This indicates direct dewatering of the Clematis Sandstone, and hence greater hydraulic connection transmitting drawdown in the aquifer.

2. Within this region, the vertical hydraulic conductivity of the Rewan Formation is modelled higher than the surrounding areas (Figure 4.6 and Figure 4.7), arising from the pilot point-based history-matching process. This allows drawdown from the deeper Permian units to transmit more easily upwards into the Clematis Sandstone.

Figure 5.5 shows the maximum modelled drawdown within the Clematis Sandstone for the SEIS A scenario. The extent of drawdown is similar to the open cut only scenario, with increased drawdown close to the mine site, above longwall panels. Drawdown extents are significantly increased for the SEIS B scenario as shown in Figure 5.6. Referring to the 0.1 m drawdown contour, this extends from approximately 23 km for the SEIS A scenario to 29 km for the SEIS B scenario, with the latter showing increased drawdown to the north-west. The increased drawdown is a result of the increased hydraulic connectivity assumed between the Permian units and the overburden sediments caused by fracturing above and a stress relief zone around longwall areas of mining .

Figure 5.7 shows the long-term post-closure drawdown in the Clematis Sandstone for the SEIS model (GHD 2013). As previously mentioned, this was extracted from a steady state simulation after the operational phase rather than from a long-term transient simulation of post-closure recovery of the groundwater system, as implemented in the updated model. The updated SEIS A scenario (Figure 5.5) is a direct comparison to the 2013 SEIS scenario from a mine schedule and longwall fracturing perspective, assuming the 2013 SEIS results approximate maximum drawdown. The 2013 SEIS scenario shows that the 0.2 m drawdown contour extends to around 25 km in the southern area, compared to approximately 18 km for the SEIS A scenario. The shape of the drawdown is also similar, showing larger drawdown emanating within the southern areas compared to the north.

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.

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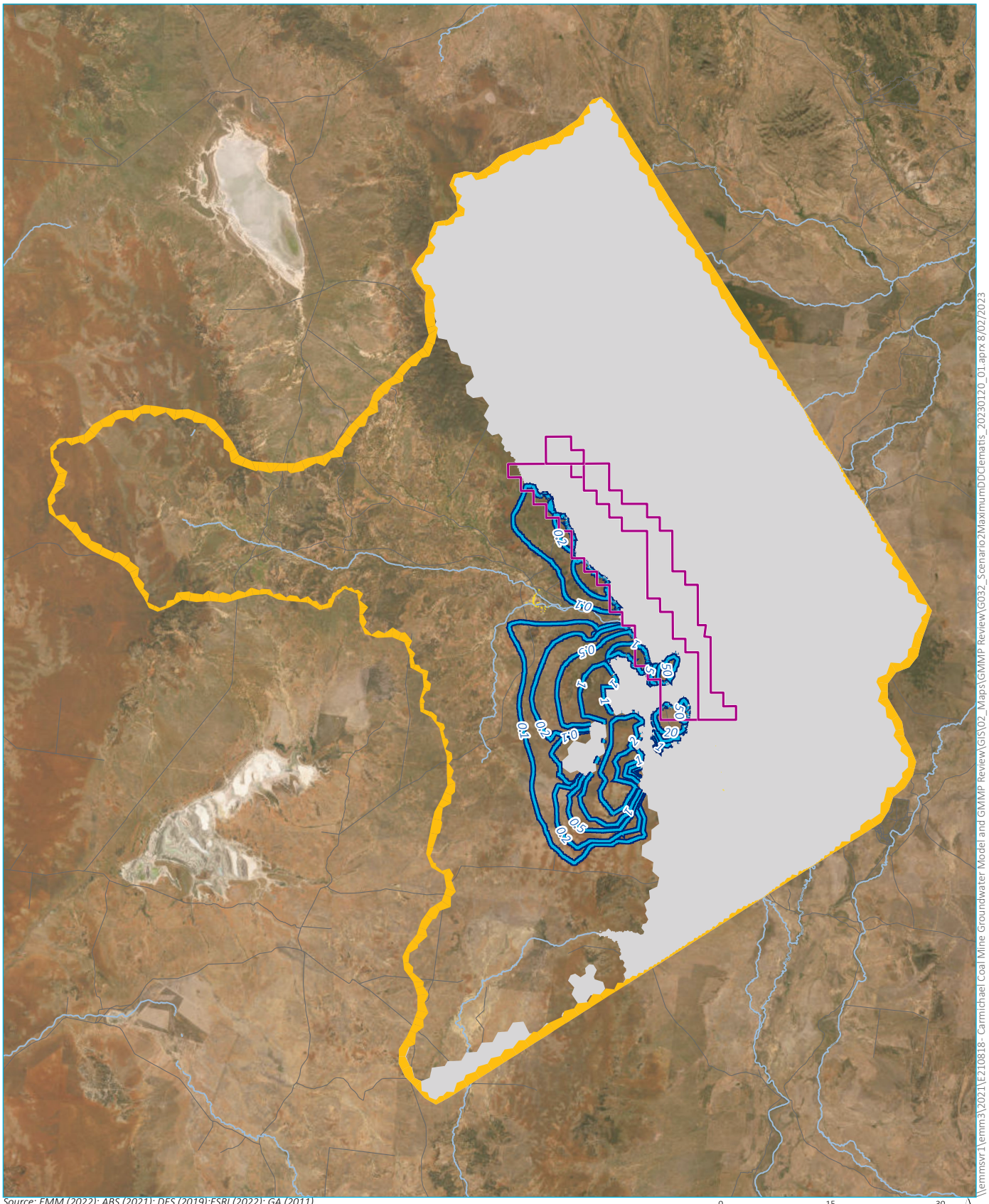


Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 15 30 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Model spring cells
- Model domain boundary
- Inactive area
- Modelled drawdown (m)
- Major watercourse
- Major road

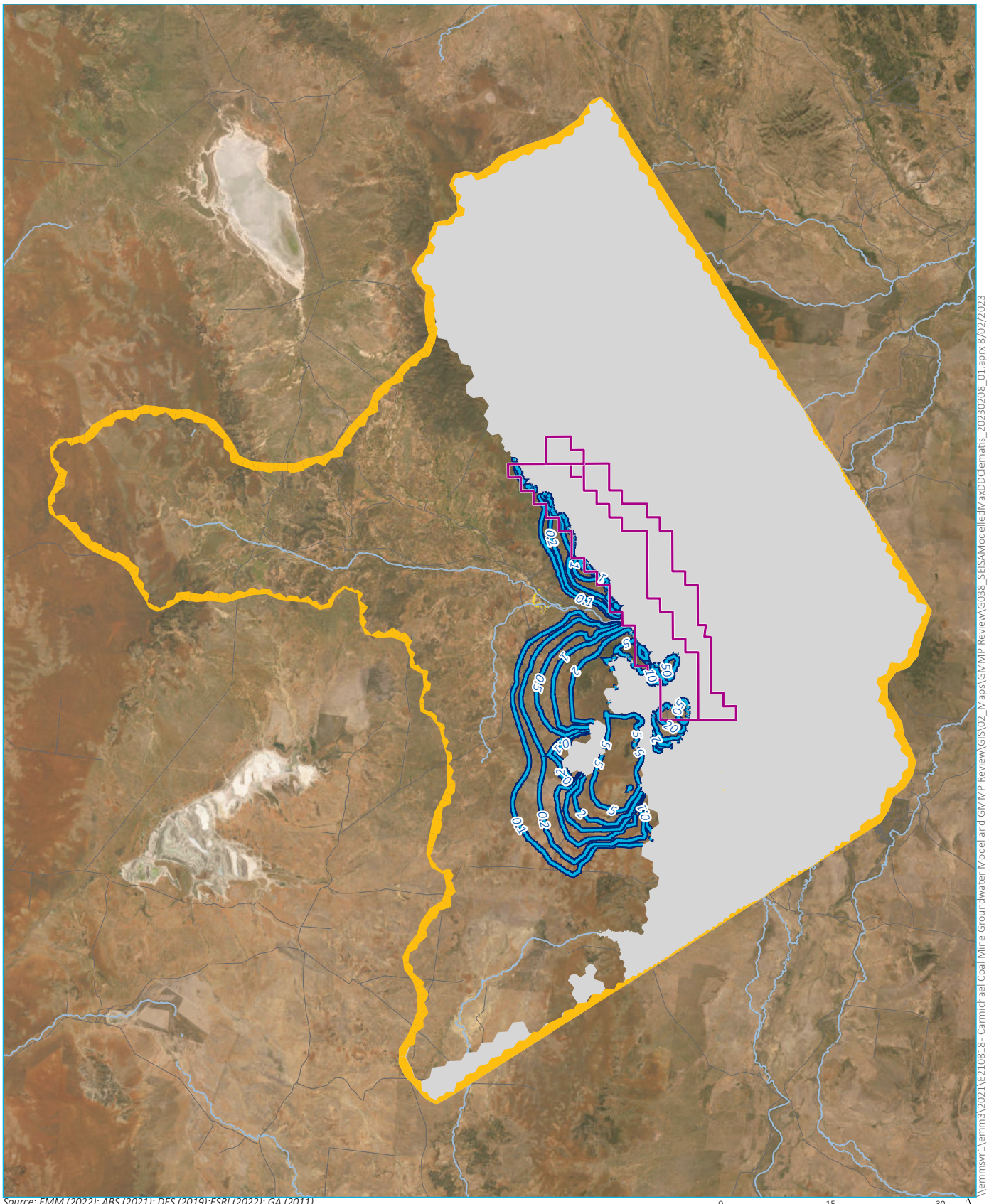
DRAFT

Open Cut only modelled maximum drawdown in Clematis Sandstone

Carmichael Coal Mine
GMMP Review
Figure 5.4

EMM
creating opportunities

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G032_Scenario2MaximumDDClematis_20230120_01.aprx 8/02/2023



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 15 30 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Model spring cells
- Model domain boundary
- Inactive area
- Modelled drawdown (m)
- Major watercourse
- Major road

DRAFT

SEIS A modelled maximum drawdown in Clematis Sandstone

Carmichael Coal Mine
GMMP Review
Figure 5.5

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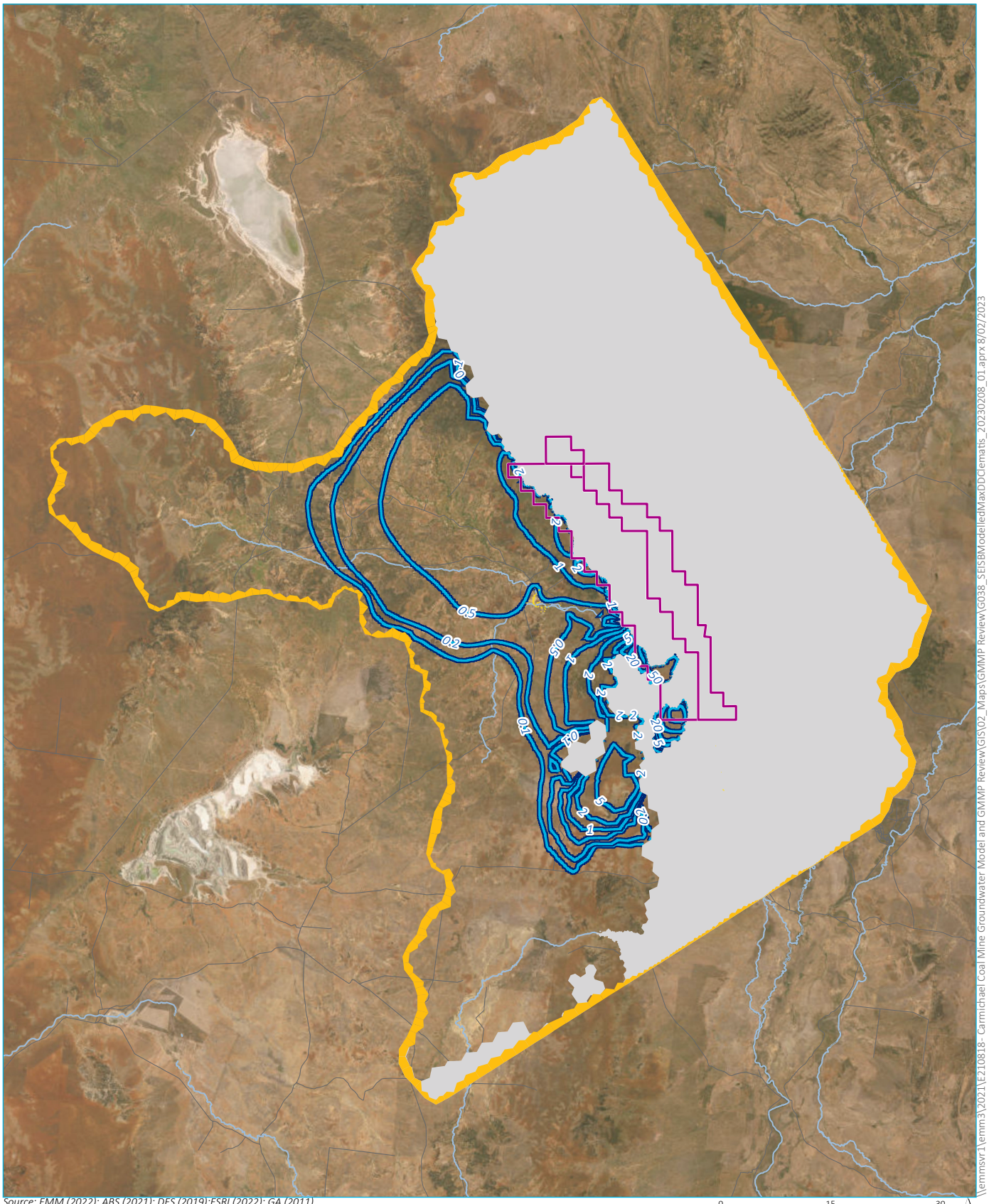


Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 15 30 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Model spring cells
- Model domain boundary
- Inactive area
- Modelled drawdown (m)
- Major watercourse
- Major road

DRAFT

SEIS B modelled maximum drawdown in Clematis Sandstone

Carmichael Coal Mine
GMMP Review
Figure 5.6

EMM creating opportunities

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G038_SEISBModelledMaxDDClematis_20230208_01.aprx 8/02/2023

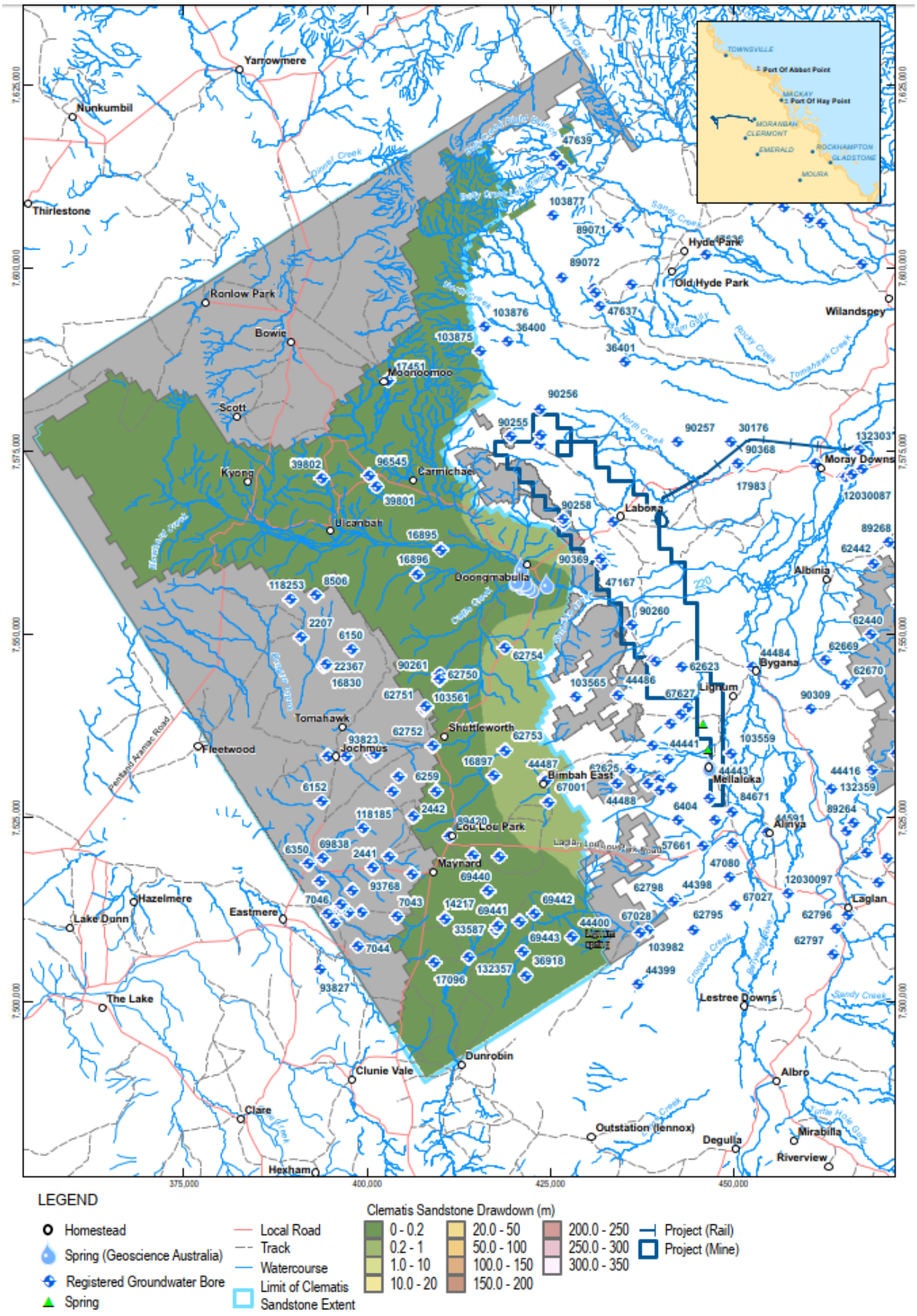
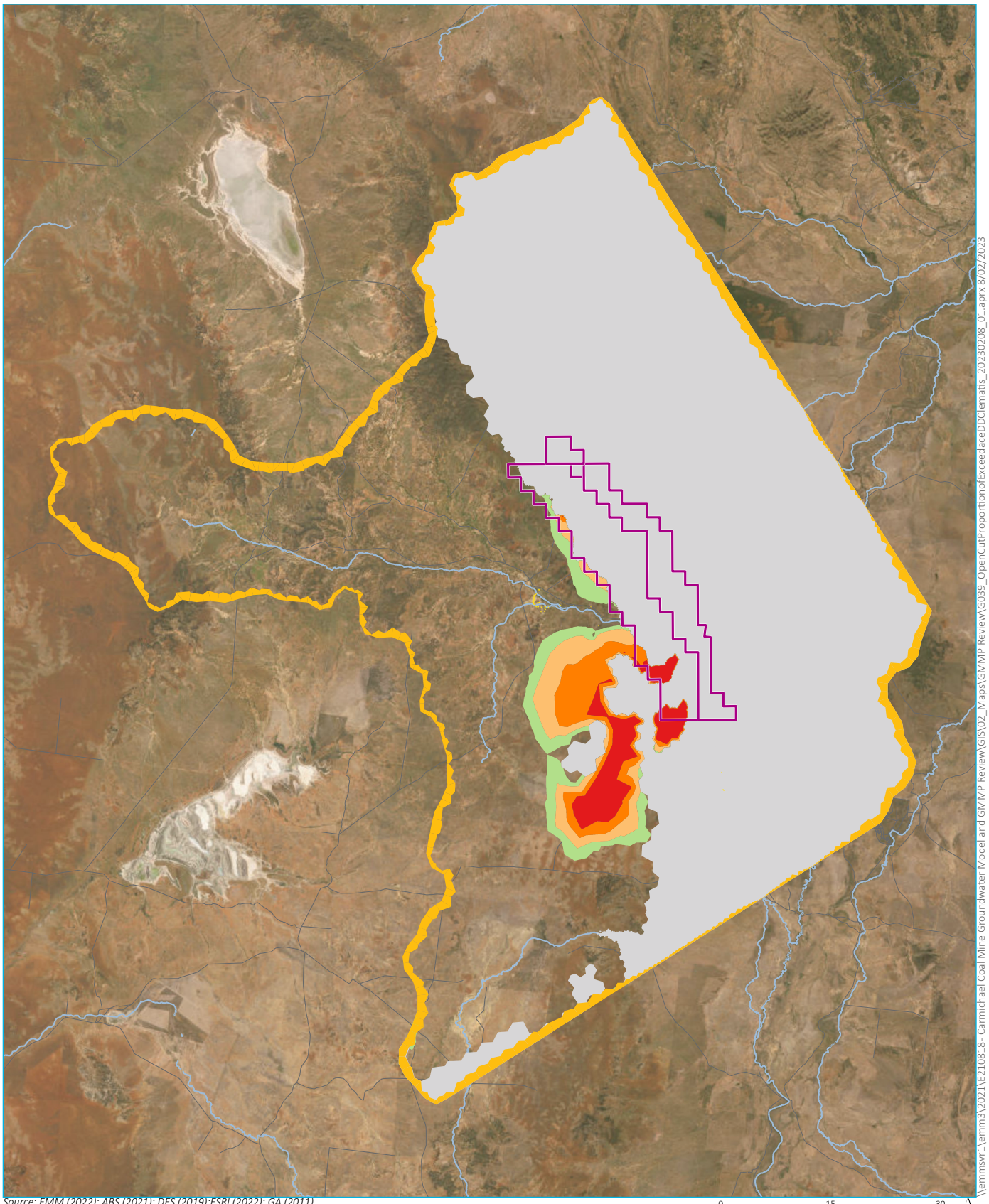


Figure 5.7 2013 SEIS modelled 'long term post closure' drawdown in Clematis Sandstone



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 15 30 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Model spring cells
- Model domain boundary
- Inactive area
- Major watercourse
- Major road

Proportion of exceedance

- P10 to P33
- P33 to P67
- P67 to P90
- >P90

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Open Cut only proportion of exceedance for 0.2 m drawdown in Clematis Sandstone

Carmichael Coal Mine
GMMP Review
Figure 5.8

EMM
creating opportunities

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G039_OpenCutProportionofExceedaceDDClematis_20230208_01.aprx 8/02/2023

ii Coal Seams

Figure 5.9, Figure 5.10 and Figure 5.11 show the maximum modelled drawdown in the AB coal seam (model layer 10) irrespective of time, for the open cut, SEIS A and SEIS B scenarios respectively. For the open cut only scenario, maximum drawdown contours of 200 m exist in the western area of the mine lease, located at the deepest part of the open cut pits. Drawdown in this region increases to approximately 300 m for the SEIS A and SEIS B scenarios, with a very minor region reaching 400 m. At this scale, the difference between the SEIS A and SEIS B scenarios is not easily discernible.

For all scenarios, drawdown within the AB coal seams extends to the western boundary of the model, a function of the high ratio between the adopted transmittivity and storage values. When compared to the previous 2013 SEIS model (Figure 5.12), the updated models show more extensive drawdown, again a function of the higher adopted transmissivity/storage ratios. As discussed earlier, these large ratios also contribute to the higher modelled inflows compared to the 2013 SEIS.

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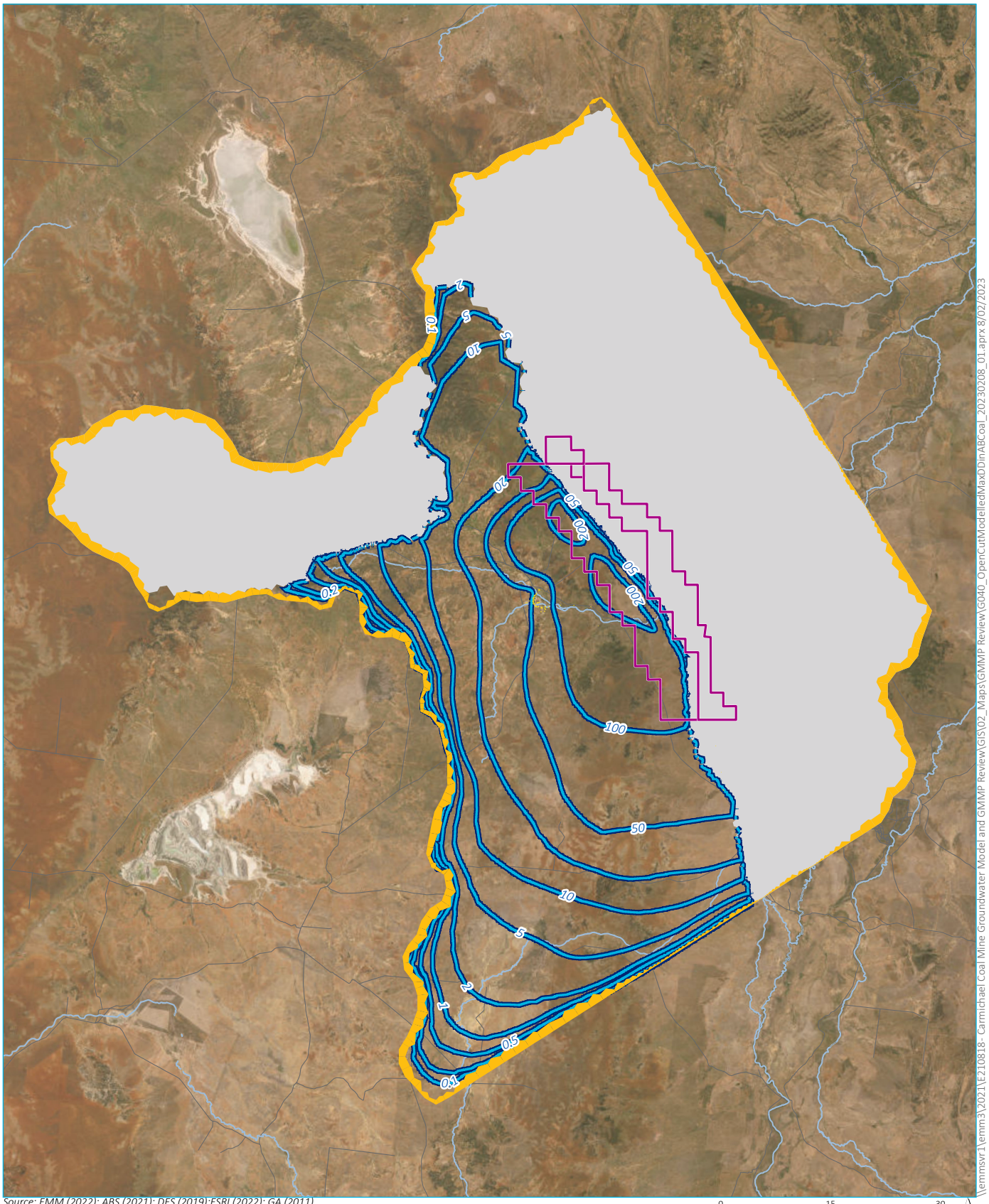

Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 15 30 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Model spring cells
- Model domain boundary
- Inactive area
- Modelled drawdown (m)
- Major watercourse
- Major road

DRAFT

Open cut only modelled maximum drawdown in AB coal seam

Carmichael Coal Mine
GMMP Review
Figure 5.9

EMM creating opportunities

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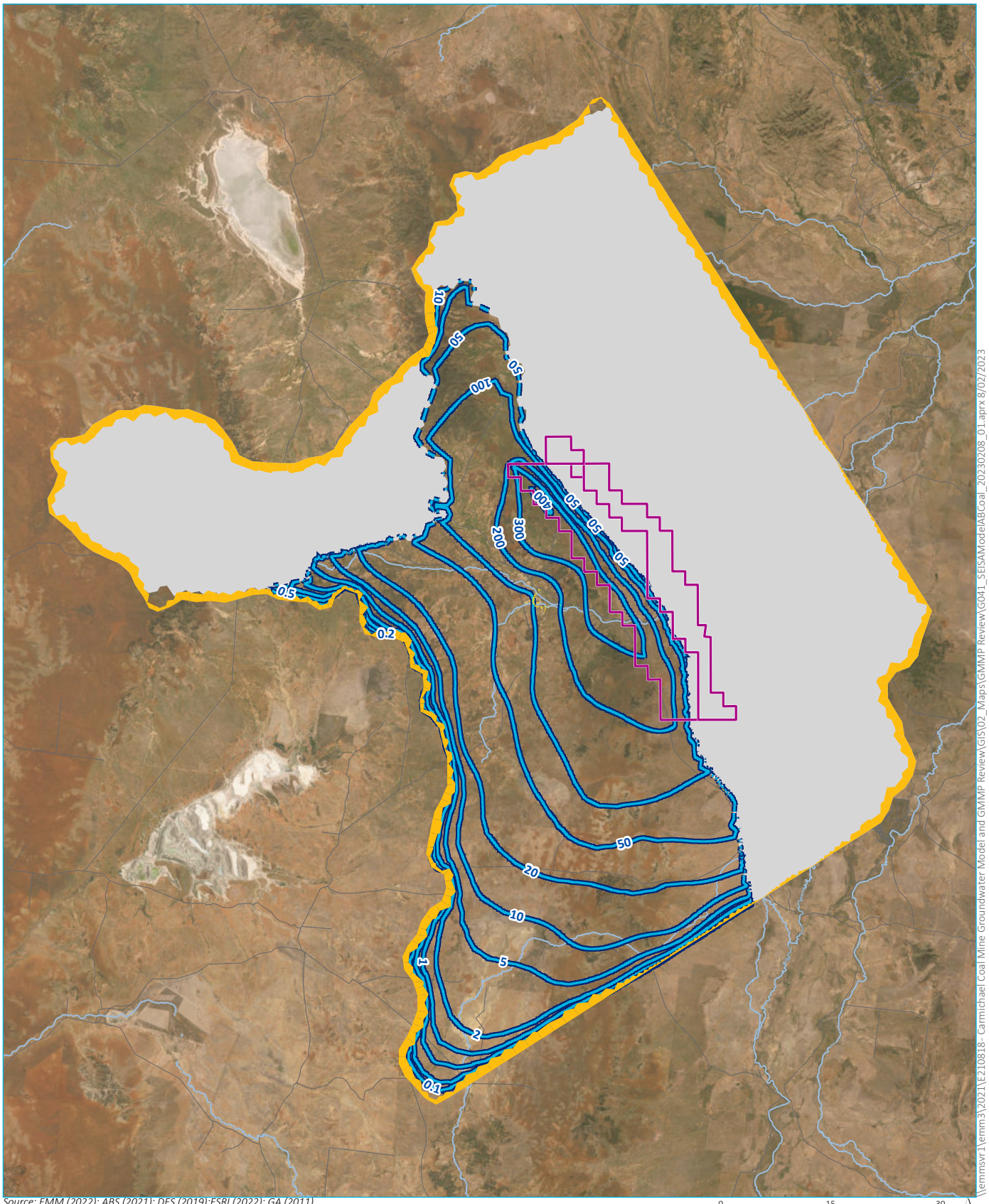

Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 15 30 km

GDA 1994 MGA Zone 55

N

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KEY

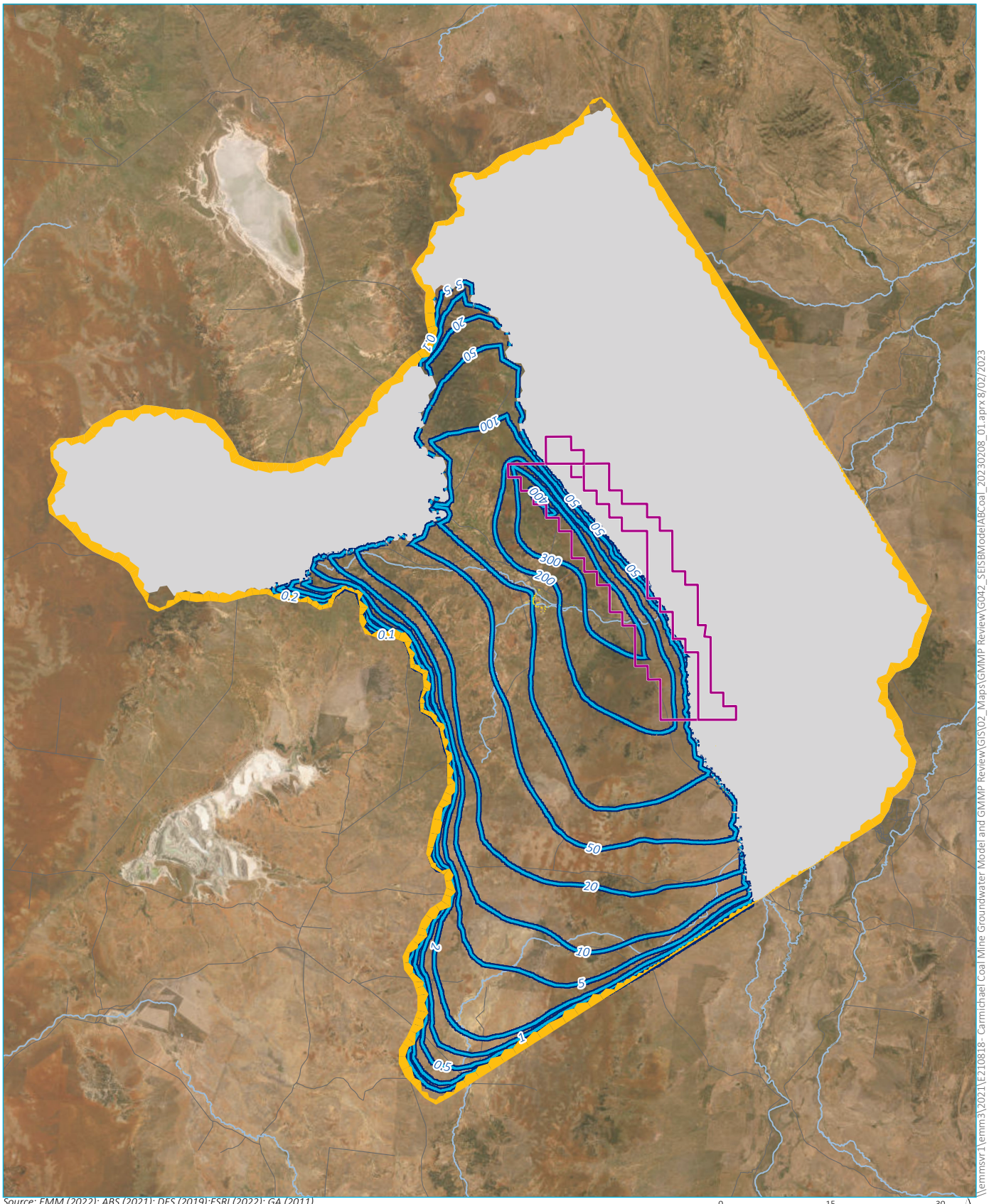
- Mining Lease
- Model spring cells
- Model domain boundary
- Inactive area
- Modelled drawdown (m)
- Major watercourse
- Major road

DRAFT

SEIS A modelled maximum drawdown in AB coal seam

Carmichael Coal Mine
GMMP Review
Figure 5.10

EMM
creating opportunities



Source: EMM (2022); ABS (2021); DES (2019);ESRI (2022); GA (2011)

0 15 30 km

GDA 1994 MGA Zone 55

N

KEY

- Mining Lease
- Model spring cells
- Model domain boundary
- Inactive area
- Modelled drawdown (m)
- Major watercourse
- Major road

DRAFT

SEIS B modelled maximum drawdown in AB coal seam

Carmichael Coal Mine
GMMP Review
Figure 5.11

EMM
creating opportunities

\\emmsvr1\emm3\2021\E210818- Carmichael Coal Mine Groundwater Model and GMMP Review\GIS\02_Maps\GMMP Review\G042_SEISBModelABCoal_20230208_01.aprx 8/02/2023

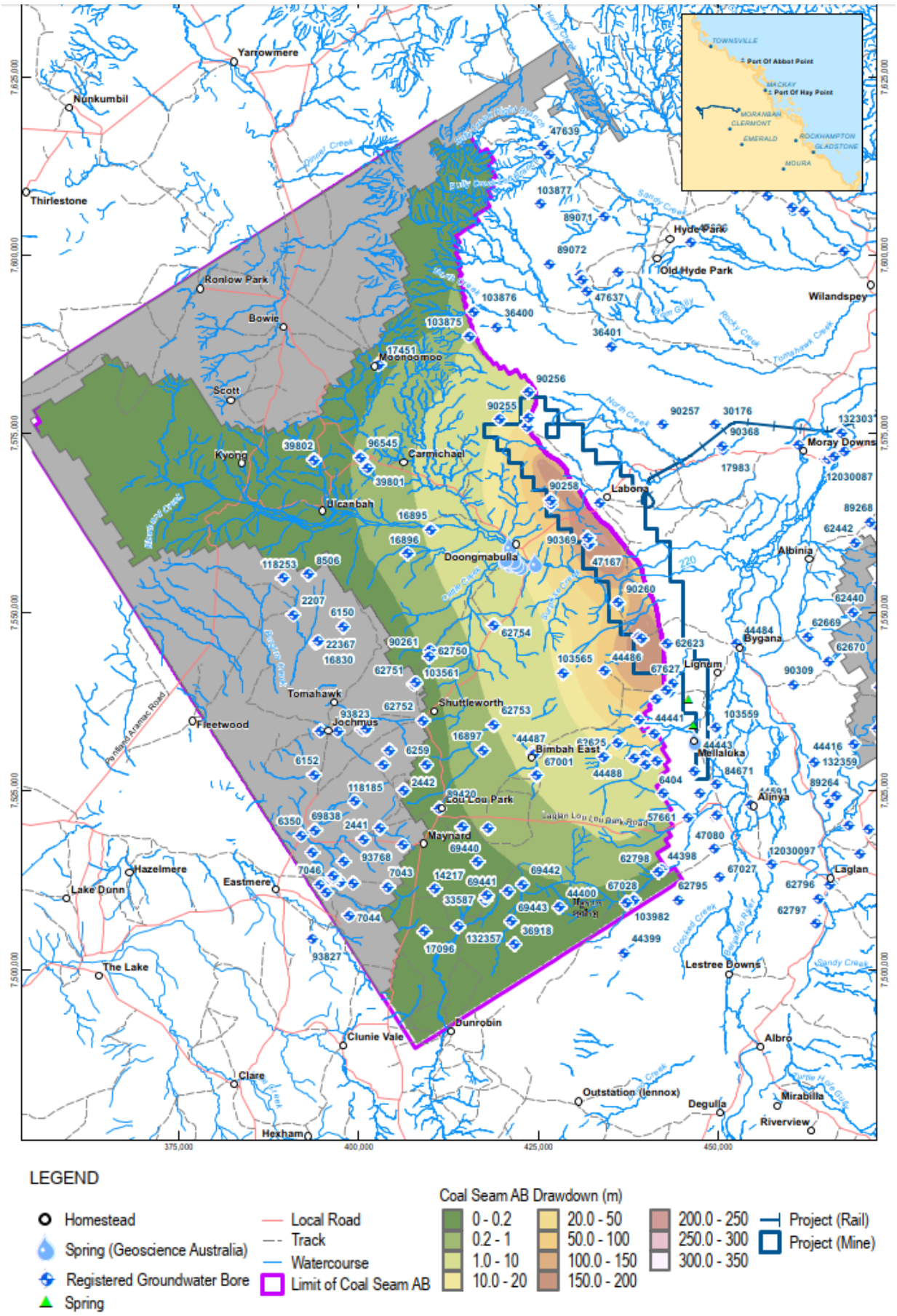


Figure 5.12 2013 SEIS modelled 'long term post closure' drawdown in AB coal seams

5.3.3 Drawdown hydrographs

A selection of modelled drawdown hydrographs over the operational and post-closure periods are shown in Figure 5.13, Figure 5.14 and Figure 5.15 for the open cut, SEIS A and SEIS B scenarios respectively. The 0.2 m spring drawdown threshold is shown as a black dashed line. Figure 5.13 also includes the full ensemble of adopted realisations, with the base case, P10, P33, P67, and P90 realisations colour coded. All drawdown hydrographs for all bores and associated realisations are shown in Appendices D, E, and F. The modelled results show the following:

- Significant drawdown is predicted in the Colinlea Sandstone and the Bandanna Formation for all scenarios.
- Groundwater levels never recover to pre-mining levels, suggesting the mine becomes a permanent groundwater sink.
- Drawdown is exacerbated within the deeper Permian units for the SEIS A and SEIS B scenarios, due to the addition of underground mining.
- The 0.2 m drawdown threshold is never breached in the Clematis Sandstone aquifer at Joshua Spring for all scenarios.
- The 0.2 m drawdown threshold is not breached in the Clematis Sandstone aquifer at the Moses 1 spring for the open cut only and SEIS A scenarios but is breached for the SEIS B scenario. This is due to the additional fracturing simulated above the underground longwall panels.
- Predictive uncertainty analysis simulates a wide range of possible drawdown outcomes at the selected bores. Uncertainty can be reduced in future modelling as more data are collected on aquifer properties and groundwater responses to ongoing mine dewatering.

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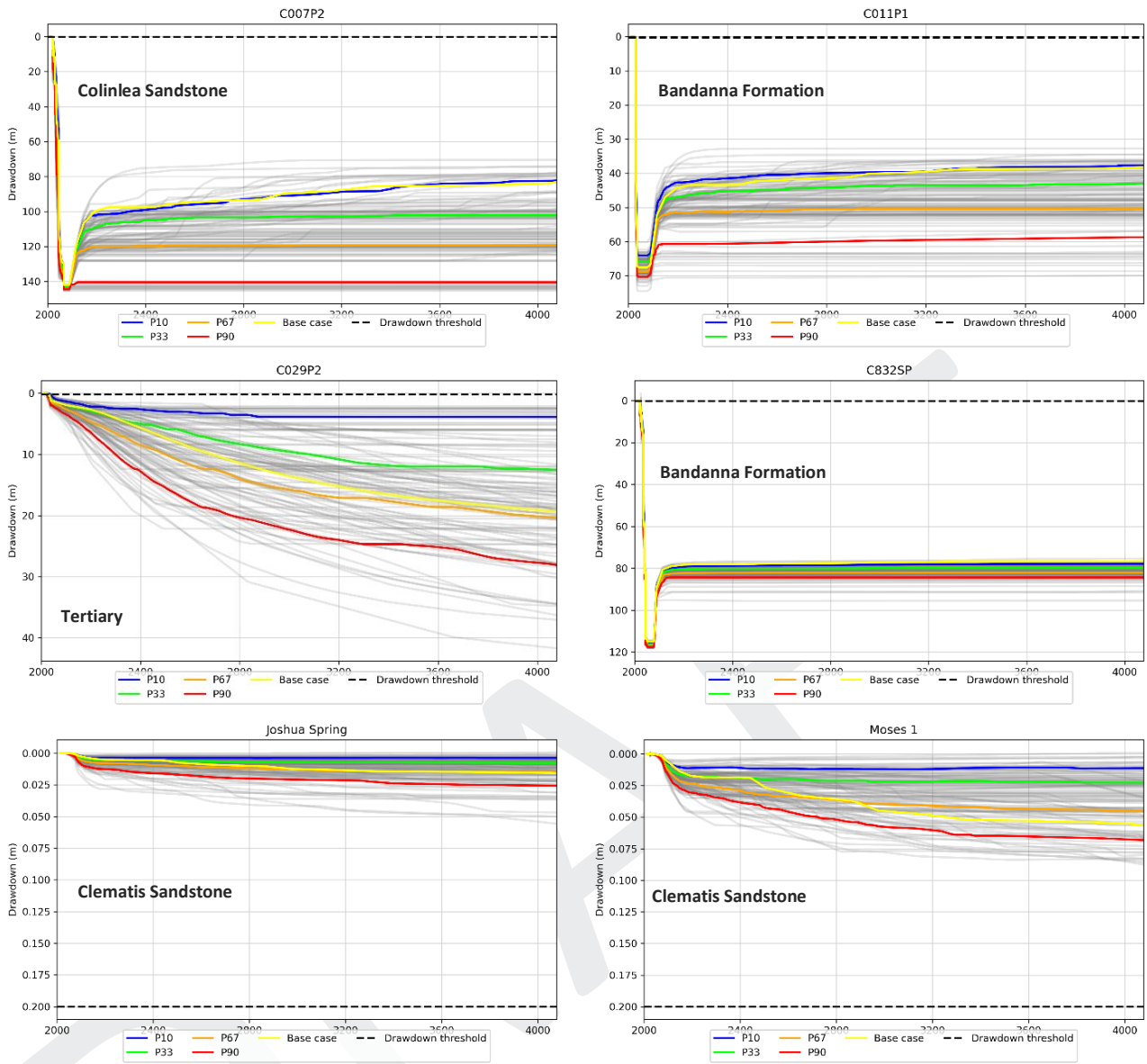

Figure 5.13 Open cut only selected modelled drawdown hydrographs

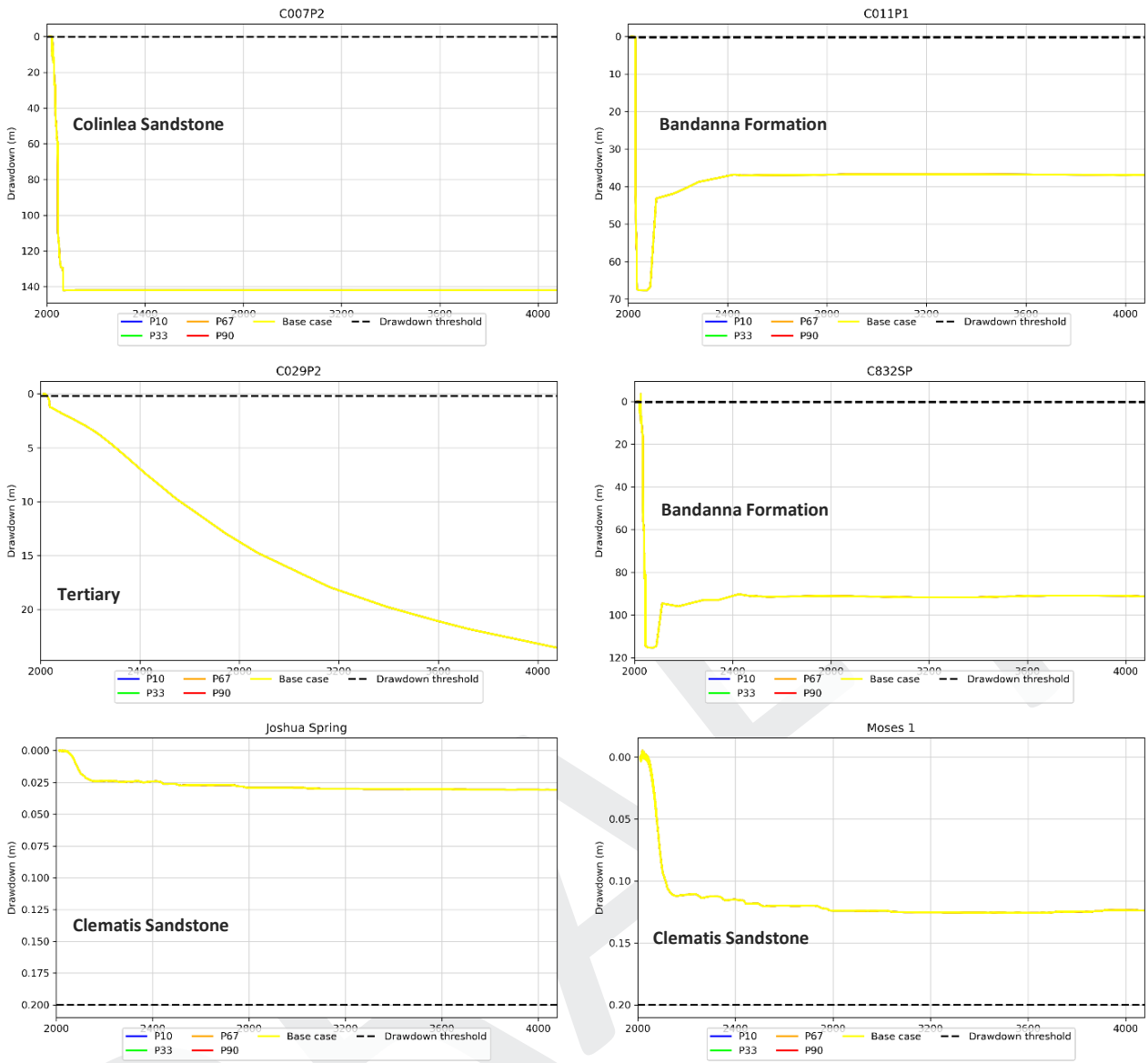

Figure 5.14 SEIS A selected modelled drawdown hydrographs

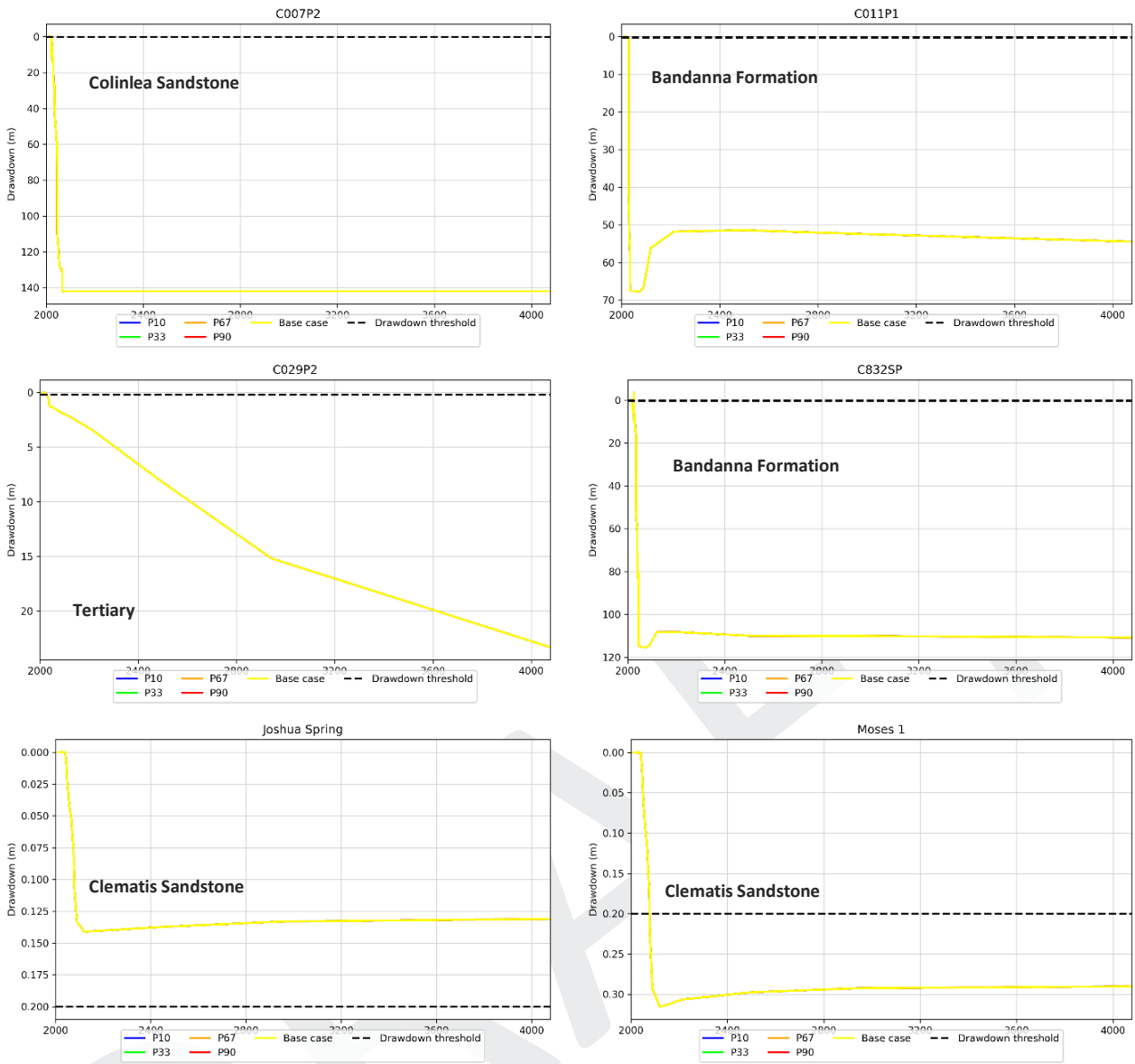

Figure 5.15 SEIS B selected modelled drawdown hydrographs

5.3.4 Drawdown at springs

Table 5.6 summaries the modelled maximum drawdown simulated at the DSC springs for the previous 2013 SEIS, and the base case realisation for the open cut only, SEIS A and SEIS B scenarios. The following is observed:

- The previous maximum drawdown simulated for the 2013 SEIS model was at Joshua Spring during the operational phase, with a drawdown of 0.19 m being predicted. All updated modelled scenarios simulate a reduced drawdown at this spring location.
- No drawdown threshold exceedances are predicted for the open cut only scenario.
- The 2013 SEIS and SEIS A base case realisation simulate similar levels of drawdown at the springs, with no spring drawdown thresholds being breached.
- The SEIS B scenario is predicted to induce drawdown exceedances at all springs, excluding Joshua Spring. The thresholds are breached by approximately 0.1 m.

- Similar to the 2013 SEIS model, larger drawdown is simulated in the southern areas for the updated model scenarios, towards the Mellaluka, Storys and Lignum spring groups.

Table 5.7 summarises the proportion of model realisations that exceed the 0.2 m drawdown threshold for the open cut only scenario. From the ensemble of 105 realisations that were simulated, not one realisation predicted drawdown larger than 0.2 m at any of the spring locations.

Table 5.6 Modelled maximum drawdown (m) at springs for the base realisation

Spring ID	Alternate ID	GHD (2013a)-operational	GHD (2013a)-post closure	Open cut only	SEIS A	SEIS B
1031_Moses4	Moses 4	<0.05	<0.05	0.05	0.12	0.29
1032_Moses3	Moses 3	<0.05	<0.05	0.05	0.12	0.29
1033_Moses2	Moses 2	0.08	0.08	0.05	0.12	0.29
1034_Littmose	Little Moses 1	<0.05	<0.05	0.05	0.08	0.33
1035_Moses1	Moses 1	0.06	0.06	0.06	0.13	0.32
1036_75E		0.09	0.09	0.05	0.12	0.29
1037_75A		0.08	0.07	0.05	0.12	0.29
1038_75D		0.07	0.07	0.05	0.12	0.29
1039_75B		0.12	0.11	0.06	0.12	0.31
1040_75C		0.12	0.11	0.06	0.12	0.32
1041_Doongma	Joshua Spring	0.19	0.16	0.02	0.03	0.14
41_(no name recorded)	Mellaluka 1	<0.05 – 1.03	1.6 – 8.39	10.90	25.27	24.19
42_(no name recorded)	Mellaluka 2	<0.05 – 1.14	2.9 – 9.07	10.95	25.28	24.24
Storie's	Storys	<0.05 – 2.34	8.2 – 13.4	18.11	34.81	33.94
Lignum	Lignum	0.06 – 8.22	14.8 – 25.6	7.30	13.54	13.15

Table 5.7 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%

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Table 5.7 Proportion of model realisations exceeding 0.2 m drawdown threshold for open cut only scenario

Spring ID	Alternate ID	Percentage of exceedance
1037_75A		0%
1038_75D		0%
1039_75B		0%
1040_75C		0%
1041_Doongma	Joshua Spring	0%

Figure 5.16 presents a comparison of modelled drawdown hydrographs for the 2013 SEIS model against the three predictive scenarios, showing the same bores on the same axes. This shows the magnitude of drawdown and long-term system dynamics following mine closure. Note the time scale for the 2013 SEIS model; the recovery stress period is shorter than for the updated model.

Modelled drawdown hydrographs for the 2013 SEIS model are broadly similar to the SEIS A scenario, with peak drawdown close to 100 m and some consistency in relative drawdown magnitude between bores. The open cut only and SEIS B scenarios bookend the predicted drawdown range, with close to two orders of magnitude difference in Permian strata. The 2013 SEIS model and all additional scenarios predict a permanently impacted groundwater system.

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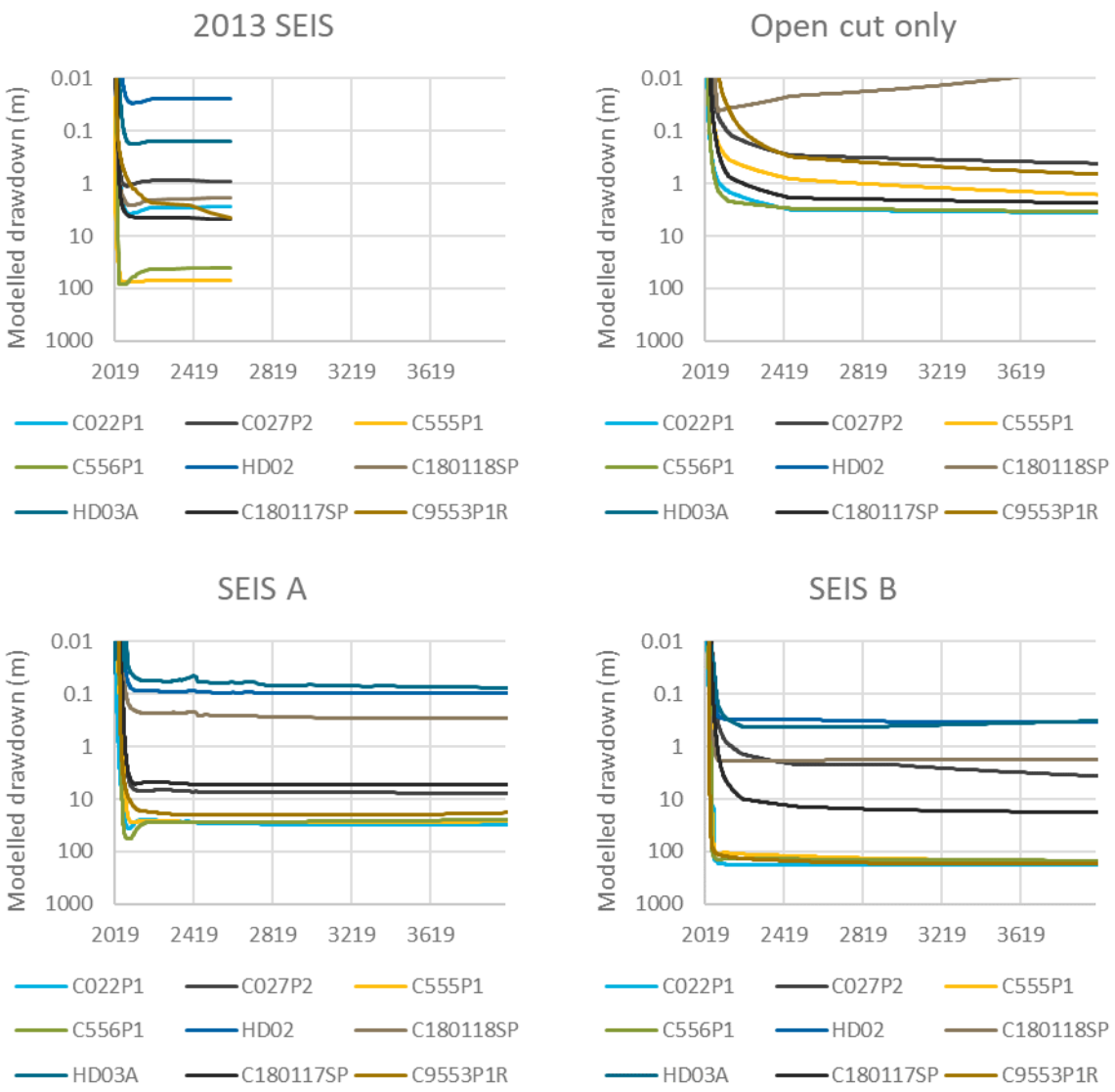
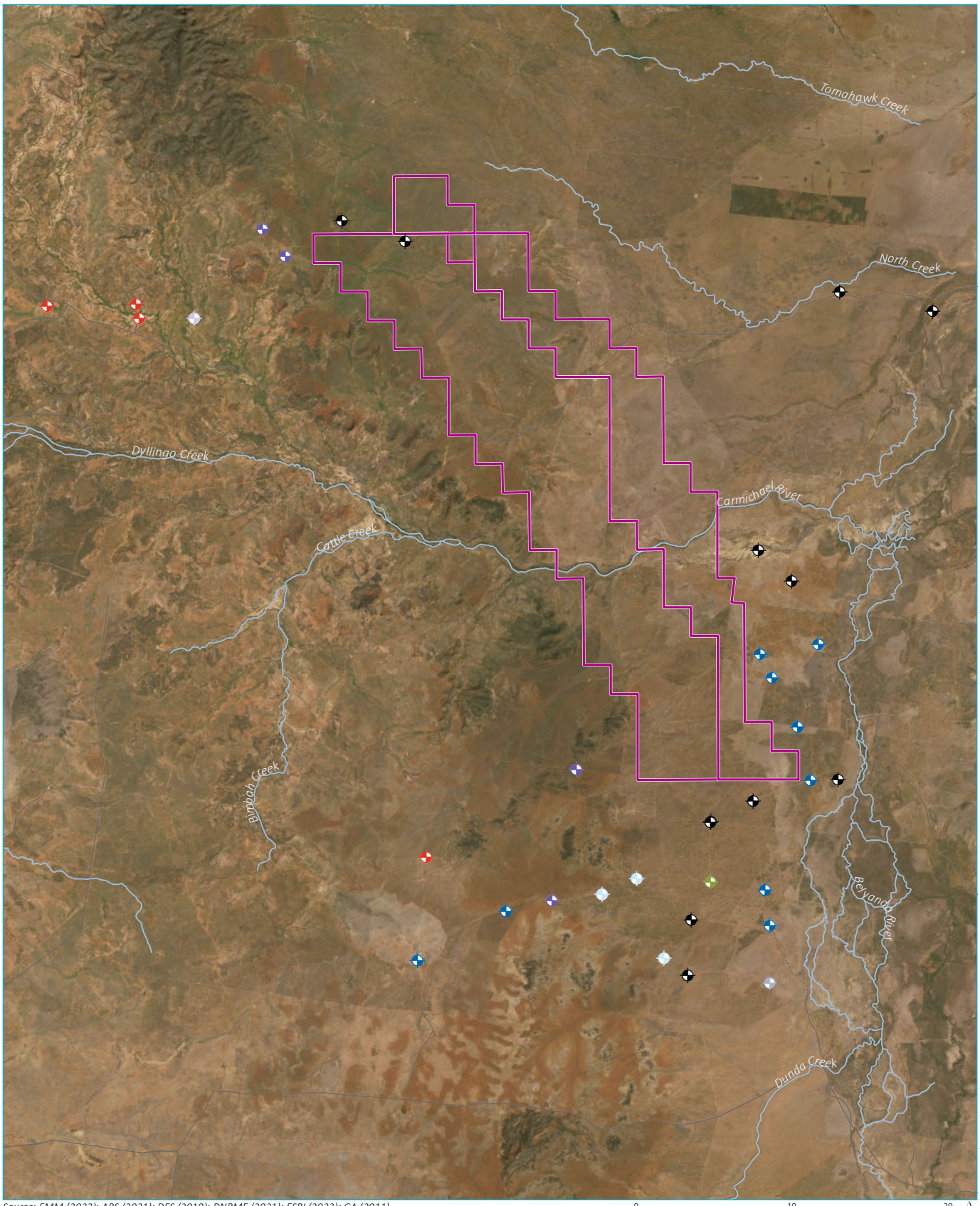


Figure 5.16 Modelled drawdown time series for 'western GAB Artesian Basin' bores - comparison between 2013 SEIS and updated model

5.3.5 Drawdown at 3rd party bores

Predicted maximum drawdown irrespective of time for active monitored third party bores is presented in Table 5.8, with a location map in Figure 5.17. Drawdown is calculated for each scenario, and comparison with results from the 2013 SEIS model included where available. As shown in hydrographs and contour maps, predictions of drawdown are highly dependent on HSU and distance from the mine. Bores screened in Permian strata are predicted to experience drawdown in excess of 100 m, whereas bores in the Clematis Sandstone may have predicted drawdown of less than 1 cm. Predicted drawdowns are broadly similar to the 2013 SEIS model and show generally increasing magnitude for each prediction scenario. There are some locations where the SEIS A scenario exhibits greater drawdown than SEIS B; this is due to the fracturing extents and property changes not being consistently greater for SEIS B than for SEIS A.



Source: EMM (2022); ABS (2021); DES (2019); DNRME (2021); ESRI (2022); GA (2011)

0 10 20 km

GDA 1994 MGA Zone 55

N

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KEY

- Mining lease
- Major watercourse
- Minor road
- Vehicular track

Third party bore

- Weathering zone
- Moolayember formation
- Clematis Sandstone/Warang Sandstone
- Dunda Beds
- Rewan Formation
- Bandanna Formation
- Colinlea Sandstone
- Joe Joe Group

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Third party bore location map

Carmichael Coal Mine
GMMP Review
Figure 5.17

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Table 5.8 Predicted drawdown (m) at 3rd party bores for base realisation

Site ID (RN)	Local bore name	Formation	Easting	Northing	GHD (2013a)-operational	GHD (2013a)-post closure	Open cut only	SEIS A	SEIS B
TBA	Dexter bore	Permian Overburden/ Tertiary	445677	7540047			7.6	11.1	10.8
103249	Desert Bore	Permian Overburden/ Tertiary	442972	7538727	8.2	85.9	7.6	12.8	12.6
158471 or 44484 (GHD 2013)	House Bore	Tertiary/Joe -Joe formation	449378	7541377			92.2	116.0	116.7
N/A	Tapgate bore	Tertiary/Joe -Joe formation	448517	7544827			96.8	116.3	116.9
N/A	Shed bore	Tertiary/Joe -Joe formation	446876	7547938			99.0	115.2	115.6
158001	Lake bore	Tertiary/Joe -Joe formation	446122	7549419			99.1	112.5	112.8
TBA	Hut bore	Tertiary/Joe -Joe formation	449869	7550061			82.1	94.5	94.8
44486	Desert Bore	Dunda Beds	434344	7542064	3.1	4.7	0.6	7.1	3.0
TBA	Clayholes bore	Clematis Sandstone	424733	7536432			0.0	0.0	0.0
44487	Bimbah House Bore	Clematis Sandstone	424155	7529828			0.2	0.3	0.3
67626	Bimbah Irrigation bore	Clematis Sandstone	424155	7529828	0.2	0.5	0.2	0.3	0.3

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Table 5.8 Predicted drawdown (m) at 3rd party bores for base realisation

Site ID (RN)	Local bore name	Formation	Easting	Northing	GHD (2013a)-operational	GHD (2013a)-post closure	Open cut only	SEIS A	SEIS B
TBA	Glens Bore	Dunda beds/Clematis (TBC)	429833	7532978			68.6	116.8	119.8
44488	Cockatoo Bore	Dunda beds	432768	7533696			1.9	9.3	7.8
62625	Soak Bore	Dunda Beds	435979	7534079	1.1	3.7	14.8	34.3	35.6
132959	Gidgea Bore	Joe-Joe formation	446731	7528369			47.1	73.8	75.3
103378	Iron Bark Bore	Rewan Formation/Dunda beds	441486	7528898			12.6	24.2	23.9
103230	3 mile bore	Tertiary/Dunda Beds	441722	7532437	0.4	28.6	6.0	12.7	12.7
103229	Desert Bore	Tertiary	442930	7538681	8.6	75.1	7.6	12.8	12.6
132961	Middle Bore	Interburden in early permian	442929	7534861			73.0	113.0	114.8
103231	Poison Bore	Tertiary/Dunda Beds	438212	7535068	4.5	38.8	24.4	48.3	49.6
103559	Stories bore	Tertiary/ Joe -Joe	446437	7534364	0.8	4.5	66.6	99.6	101.1
90212	Shellys bore	Rewan Formation/Dunda beds	439949	7529980			10.1	24.3	24.2
44443	House bore	Tertiary/ Joe -Joe	446729	7532074			92.2	116.0	116.7
103680	Gold Lotto	Tertiary/Sand stone	446002	7556100			25.1	29.9	28.6

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Table 5.8 Predicted drawdown (m) at 3rd party bores for base realisation

Site ID (RN)	Local bore name	Formation	Easting	Northing	GHD (2013a)-operational	GHD (2013a)-post closure	Open cut only	SEIS A	SEIS B
158649	Satr Light	Tertiary/Sand stone	448146	7554149			28.8	34.5	34.1
17983 (TBC)	Eight Mile Bore	Tertiary (TBC)	451231	7572656			2.0	7.8	2.3
17981 (TBC)	10 Mile Bore	Tertiary (TBC)	423365	7575902	18.1 (Permian Sandstone, L10)	23.6	37.4	38.5	38.5
90255 (TBC)	15 Mile bore	Tertiary (TBC)	419310	7577204	0.8 (Clematis/Dunda)	0.8	2.3	28.9	53.9
TBA	Yambina Bore	Tertiary (TBC)	457184	7571423			0.7	4.4	1.4
TBA	Crazy Bore	Dunda beds	414230	7576676			0.1	1.1	2.8
TBA	Wild Bore	Dunda beds	415707	7574934			0.0	0.6	2.8
103423	Gidgea No.1 Bore	Assumed above Clematis	446731	7528369	n/a (new bore)	n/a (new bore)	24.5	54.3	53.9
132960	Gidgea No.2 Bore	Clematis (assumed)	446731	7528369	n/a (new bore)	n/a (new bore)	44.2	69.5	71.0
TBA	Carmichael House Bore	Moolayember or Clematis	406312	7570944	n/a (new bore)	n/a (new bore)	0.0	0.0	0.7
TBA	Kades Bore	Moolayember or Clematis	406128	7571872	n/a (new bore)	n/a (new bore)	0.0	0.0	0.7
TBA	Cow Paddock Bore	Moolayember or Dunda	409855	7570961	n/a (new bore)	n/a (new bore)	0.0	0.0	0.5
96545	Mosquito Bore	Moolayember or Clematis	400432	7571736	n/a (new bore)	n/a (new bore)	0.0	0.0	0.5
158631	Riverlane Bore	Tertiary	451106	7541406	n/a (new bore)	n/a (new bore)	12.8	18.1	17.7

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5.3.6 Predicted baseflow assessment and comparison to 2013 SEIS model

Modelled baseflow and associated changes following mining for the 2013 SEIS model and the three predictive scenarios are presented in Table 5.9. The SEIS groundwater model predicted a steady-state baseflow of 7 ML/d, whereas the updated model predicts 1.9 ML/d. The modelled reduction in baseflow is greatest for the 2013 SEIS model, in large part due to the difference in starting conditions between model versions. The updated groundwater model predicts a smaller change in baseflow, with an upper value for the SEIS B scenario of 135 kL/d, equivalent to a 7.1% reduction compared to pre-mining conditions.

Table 5.9 Predicted baseflow assessment

	2013 SEIS model	Open cut only	SEIS A	SEIS B
Baseflow – steady state (m^3/d)	7,084	1,890	1,890	1,890
Baseflow change – end of operation (m^3/d)	Not reported	1.1	3.7	87.8
Baseflow change – long-term recovery (m^3/d)	648.0	1.9	3.1	135.0
Baseflow percentage change	9.15%	0.10%	0.16%	7.14%

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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 had been reviewed by a range of scientists. A summary of review elements has been previously compiled and documented in EMM 2022a. Individual comments and recommendations are presented in Table 6.1 along with responses following model design, history-matching, predictions and uncertainty analysis.

Table 6.1 Approach to address past project criticism

Author/reference	Summary of comments	Data/research/approach
URS 2013b	Field data could have been better integrated into conceptual model, to determine a set of preferred values and ranges for hydraulic conductivity and storage. No storage calibration from steady state model – literature values used. Water balance with high recharge loss. Heterogeneous hydraulic conductivity across layers. Issues raised include: Cumulative percentage discrepancy, stream leakage and baseflow, model parameter variation due to longwall mining, and post closure water balance. 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. Are higher potentiometric pressures to the north and south considered for the flow in the report, are enhanced recharge, or structures considered? 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. 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 5 mm/yr. 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. 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.	Hydrogeological conceptualisation has been updated to address the key issues raised by this document, including: • 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 Formation, 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

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Table 6.1 Approach to address past project criticism

Author/reference	Summary of comments	Data/research/approach
	The Rewan Group as a unit is important for model predictions on the GAB, additional discussion on the sensitivity results should be provided. No source of data or assumptions on the geology outside of the mine lease. Model convergence criteria might be too high at 1 x 10^{-2} m, typically 1 x 10^{-3} m is used. Elevated water balance errors in some stress periods of the predictive model represents a genuine shortcoming of the current model. Does hydraulic conductivity vary with depth? The calibration does not show if the vertical hydraulic gradients were preserved at locations that had multi nested monitoring points. 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? How were SW/GW interactions assessed in the steady state model for the dry season outside of the mine lease? Please explain how the recharge rate was determined and provide discussion on the effective recharge. Please explain how a robust predictive model can be generated from the current steady state model calibrated to average head data only. 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. A low value of residual saturation was used for the unsaturated zones at 5 x 10^{-3}. Large mass balance errors were identified at some stress periods, as such the predictive model outcomes are questioned. 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. 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. A mine plan with schedule was not provided. For a 5 year mine plan, how was it applied, equally in yearly increments? No uncertainty analysis was detailed or discussed in the report, an uncertainty analysis could provide additional confidence in model predictions with	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. The updated conceptualisation has been incorporated into the groundwater flow model (GWFM) with the following review comments addressed: • Sensible modelled fluxes and low water balance errors cumulatively and for discrete time intervals. • Transient history-matching, incorporating flux targets for SW-GW interactions has been undertaken as per Section 4.2.5. Modelling shows that the Carmichael river is mainly a losing system, consistent with the conceptualisation. Model also calibrates well to estimated spring discharge (Section 4.2.6). • Highly parameterised approach to history-matching using pilot points and PESTPP-IES, with parameter bounds guided by (but not restricted to) field data as described in Section 4.1.3. • Hydraulic conductivity reduction with depth in accordance with the conceptualisation, nominally for Rewan Formation but also for other HSUs where supported by observed data. • Detailed history-matched (posterior) analysis of modelled aquifer parameters. • Time-varying material properties have been included for the mined coal seam, and the fractured zone above the coal seams. For the updated model (SEIS B scenario), further changes were invoked including updates recommended from the Rewan Research study and the use of a ramp function (Merrick 2017) as described in Sections 3.5.5 and 5.1. • Type 3 predictive uncertainty analysis has been presented (Section 5), with the open cut only scenario presenting the outcomes of 105 realisations.

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Table 6.1 Approach to address past project criticism

Author/reference	Summary of comments	Data/research/approach
	regards to: storage, hydraulic conductivity and storage after longwall mining, groundwater ingress, and climate change. Recommendations: • 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, which 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.	
IESC 2013	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. 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. 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. 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. The conceptual model would benefit from an assessment of regional faults.	Hydrogeological conceptualisation has been updated to address the key issues raised by IESC and is detailed in EMM 2022 and summarised in Section 2 on this report. This includes: • 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 in EMM 2022a and is documented in Merrick 2021b. • Subsidence-induced fracturing was a major component of the Rewan connectivity research program. Findings from that research have informed the revised HCM documented in EMM 2022a and assumed modelling properties documented in Section 5. • The GAB Springs Research program is leading to more defined understanding of how the DSC functions. New monitoring bores, VWPs, hydrochemical and isotope 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

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Table 6.1 Approach to address past project criticism

Author/reference	Summary of comments	Data/research/approach
	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. 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. 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. 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. There remain important data gaps and modelling inaccuracies which bring into question the hydraulic conductivity values employed by the model. 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. 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. 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. 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. 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. Groundwater flow in deeper aquifers would be anticipated to conform to the generally recognised regional westerly flow within the GAB from the	leading to pressures building up over geological time and driving discharge to those springs. • 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 have been analysed since the SEIS. Detailed analysis of Kx and Kz with depth across the Rewan aquitard has been undertaken. Integrated K datasets have established field-based statistical ranges for each HSU, which have been carried forward as part of the PEST history-matching process (Section 4). Updates to GWFM include: • Calibrated HSU parameters are more closely tied to field data and statistics (see Section 4.1.3) • Regional boundary conditions are discussed in Section 3.5 and are based on interpreted regional groundwater pressures and flow regime. The regional groundwater flow regime is also discussed in EMM 2022a. • Detailed uncertainty analysis incorporating potential connectivity between the GAB and the coal seams has been based in part on data collected as part of Research Package 5. This has been further explored by undertaking a highly parameterised approach to HSU property distribution and has been assessed using detailed uncertainty analysis aligned with considerations from Middlemis and Peters 2018. • Revision of the groundwater model, by taking into account various studies' outputs from both the recent Rewan and GAB Research Projects, has enable a more rigorous assessment of potential impacts on the Doongmabulla and Mellaluka Springs Complexes.

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Table 6.1 Approach to address past project criticism

Author/reference	Summary of comments	Data/research/approach
	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. 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. 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. 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. 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.	
Hydrogeologic 2014	Transient calibration has not been undertaken, which is a model shortcoming that has been addressed via comprehensive sensitivity and uncertainty analysis. 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. 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). 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 Clematis bores would require increased boundary inflows from the south and/or increased rates of modelled Clematis recharge, and/or aquifer parameter changes. 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	Hydrogeological conceptualisation has been updated to address the key issues raised by Hydrogeologic, including: • 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. There are also vertical gradients within the Clematis Sandstone unit, suggesting a complex system, which may not be able to be simulated accurately on a reginal scale. • 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. • 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

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Table 6.1 Approach to address past project criticism

Author/reference	Summary of comments	Data/research/approach
	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). 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. 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. 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). 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. 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. 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. 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.	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 and used to inform model parametrisation accordingly. • 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 Formation, 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. The updates to GWFM include: • Active groundwater modelled area has been updated and reviewed based on detailed geological mapping and modelling. Inactive cells are located only in areas where units are interpreted not to exist. • Additional vertical refinement of model layers in the area of mining have been included to represent decreasing hydraulic conductivity with depth. • Colinlea Sandstone layer has been split to areas above D-seam, D-seam explicitly and all areas below D-seam. • Transient calibration to groundwater heads, changes in head and fluxes where available have been used. • Calibration has been undertaken initially using a zoned approach, followed by a highly parameterised approach, guided by conceptualisation and data availability. • Updated recharge from rainfall, spring discharge and river leakage incorporated based on updated conceptualisation (EMM, 2022a) as discussed in Section 3. This includes episodic recharge rates. • Updated stress period durations have been implemented during the prediction period that a) more appropriately represents the mine plan, and b) captures the wet and dry seasonality. The predictive mine plan is simulated with 109 part-year stress periods (8 months and 4 months respectively), representing dry and wet seasons.

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Table 6.1 Approach to address past project criticism

Author/reference	Summary of comments	Data/research/approach
		• Updated model explicitly simulates post-closure pit void (Section 3), including time-varying material properties, direct incident rainfall and evapotranspiration surface based on pit base dimensions and elevation.
GHD 2015	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. 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. 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 (i.e. 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). As the project continues to evolve, the groundwater model will continue to be updated to reflect advances in understanding of the regional hydrogeological conditions. 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). 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: • 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. • 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,	Hydrogeological conceptualisation has been updated to address the key issues raised by GHD (2015), including: • 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. Updates to GWFM include: • Updates to HCM and thus model design, including explicit representation of weathered zone (EMM 2022a). • Enhanced horizontal and vertical discretisation in the vicinity of the mine using Voronoi mesh (Section 3). • Colinlea Sandstone layer has been split to areas above D-seam, D-seam explicitly and all areas below D-seam. • Transient calibration with updated head and head-change targets, including surface water discharge fluxes where available (Section 4). • Transient recharge fluxes representing climate during history-matching period, with appropriate assumptions for the prediction phase (Section 4). • Detailed predictive uncertainty analyses undertaken, paying particular attention to exceedance probability related to spring drawdown thresholds (Section 5).

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Table 6.1 Approach to address past project criticism

Author/reference	Summary of comments	Data/research/approach
	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. 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.	
CSIRO 2019	The review found that the modelling used is not suitable to ensure the outcomes sought by the EPBC Act conditions are met. 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. 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. 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. 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. 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: • 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. Recommendations: • Future updates of the model should also use stream flow as one of the calibration parameters. • Guidance for uncertainty analysis should be considered in future model updates.	Hydrogeological conceptualisation has been updated to address the key issues raised by CSIRO, including: • 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 have been undertaken as part of the comprehensive Rewan research study. Detailed analysis of Kx and Kz with depth across the Rewan aquitard has been assessed. Integrated K datasets have established field-based statistical ranges for each HSU and incorporated into the updated model. • Drilling and installing monitoring sites to the west of the lease area has been undertaken, 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. Updates to GWFM include: • Total rebuild of the HSUs based on updated geological mapping and modelling. • History-matching to all available data, including fluxes to surface water. • CSIROs statement concerning modelled fluxes from the previous SEIS model seem inaccurate. The previous model simulated a mainly gaining system and did not allow significant recharge to occur to the alluvium sediments. The updated HCM and model suggest large recharge occurs from the rivers to the aquifer during the wet season. • Any changes in model bore heights have been previously documented and updated reduced levels have been used in the updated modelling project. • History-matching undertaken using pilot pints and PESTPP-IES to be consistent with

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Table 6.1 Approach to address past project criticism

Author/reference	Summary of comments	Data/research/approach
	• 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. • Recalibration should include revised bore heights to provide confidence that captured evapotranspiration is not limiting drawdown to the DSC and the Carmichael River GDE. • model updates should use locally appropriate parameterisations. • Sensitivity analysis undertaken for future model updates should seek to assess cumulative sensitivity. • updates should include analysis of the sensitivity of the model to parameter changes due to underground mining. 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. 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. 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. 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).	parameter ranges outlined in the HCM (EMM 2022a and Section 4). • Type 3 (Monte Carlo) predictive uncertainty analysis completed on open cut only scenario. Uncertainty related to mining-induced hydraulic parameter changes have not been completed to date.

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7 Summary and recommendations

The main summary points from the updated modelling study include:

- The model has undergone a significant rebuild to meet Environmental Authority (EA) Condition E9, while addressing past review comments of the SEIS.
- The model rebuild aligns with updated conceptualisation and datasets including an updated geological model, groundwater pressures, groundwater drawdown and mine dewatering rates. Knowledge from the RFCRP and GABSRP (i.e. spring conceptualisation and discharge volumes) has also been incorporated.
- 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.
- Model history-matching and predictive uncertainty analysis used pilot points and PESTPP-IES with 105 accepted parameter realisations developed for the open cut (OC) only scenario.
- The updated modelled mine inflows are far greater than the previous 2013 SEIS model, largely due to the history-matching process estimating larger hydraulic conductivity and storage values for the Permian sediments.
- Results predict that the OC scenario will not breach the DSC drawdown threshold of 0.2 m for the base case or any of the full ensemble of realisations.
- Although the OC base case and full ensemble 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 and properties invoked for the Rewan Formation, specifically vertical hydraulic conductivity.
- Modelling of the SEIS mine plan using the previous model fracturing assumptions (SEIS 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 2013 SEIS model results.
- Modelling of the full SEIS mine plan using updated fracturing and relief zone assumptions (SEIS B), results in base case drawdowns that breach the 0.2 m drawdown threshold on the order of 5-10 cm.
- Predicted impacts to landowner bores are expected to range from minimal interference to greater than 100 m drawdown.
- Predicted reduction in baseflow to the Carmichael River is expected to be minimal for OC mining only and up to 135 kL/d for the SEIS B scenario, equating to a reduction of 7.1% compared to pre-mining.

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).

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- 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 open cut F and G pits. This is in addition to previously recommended bores being installed in the western portion of the mining lease, east of the DSC.

- Further studies should concentrate on aquifer analysis related to Permian drawdown. The next 5-year model review will include a significant dataset related to Permian drawdown in response to ongoing mine dewatering and, thus, future history-matching can be better informed by this dataset.

- 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, the 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, the underground mining areas, it recommended the GMMP develops groundwater drawdown thresholds that are associated with the OC only mining scenario, 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 spring drawdown thresholds.

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Appendix A
Monitoring bores

EMM
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Appendix B

Modelled parameter frequency distributions

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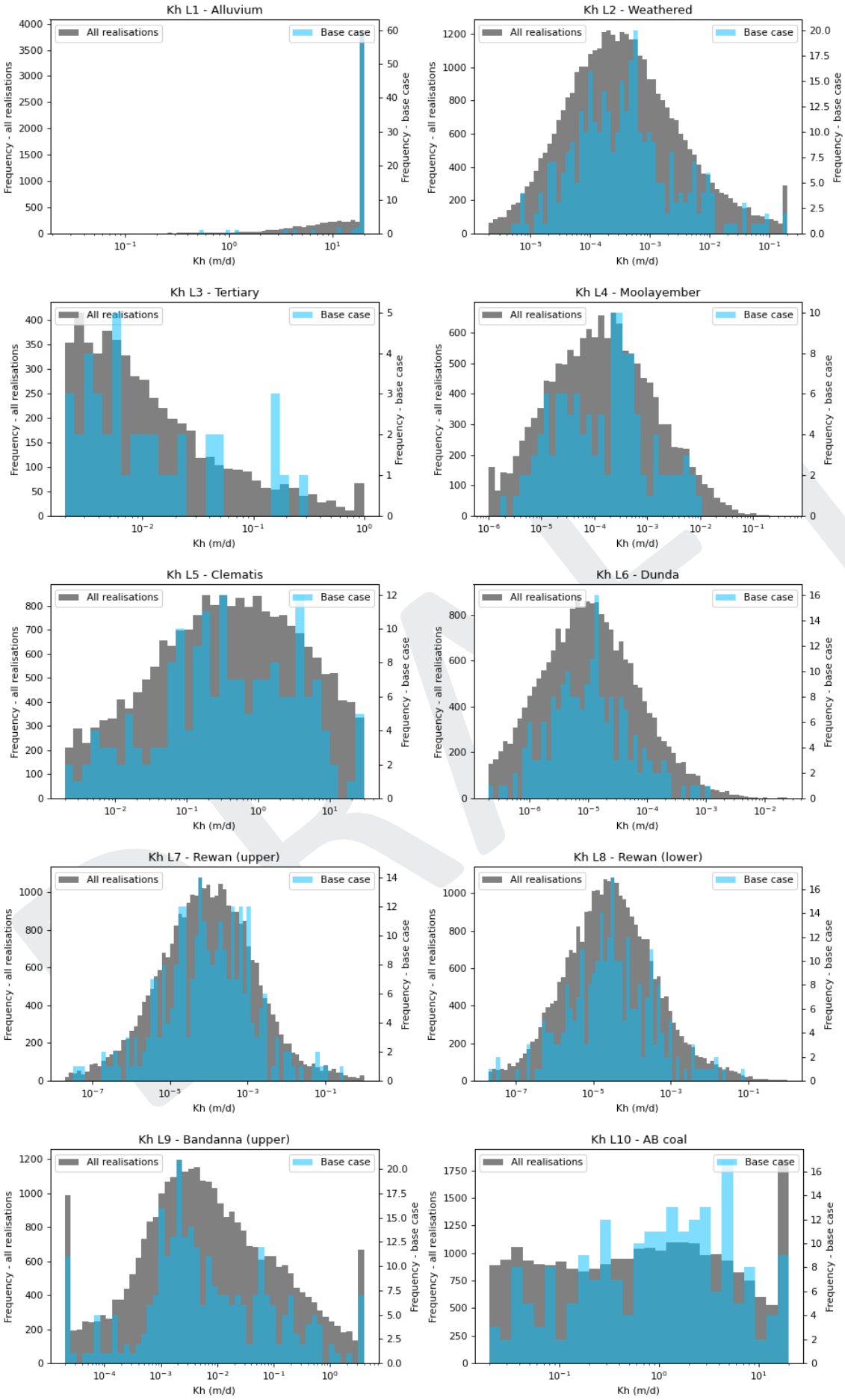
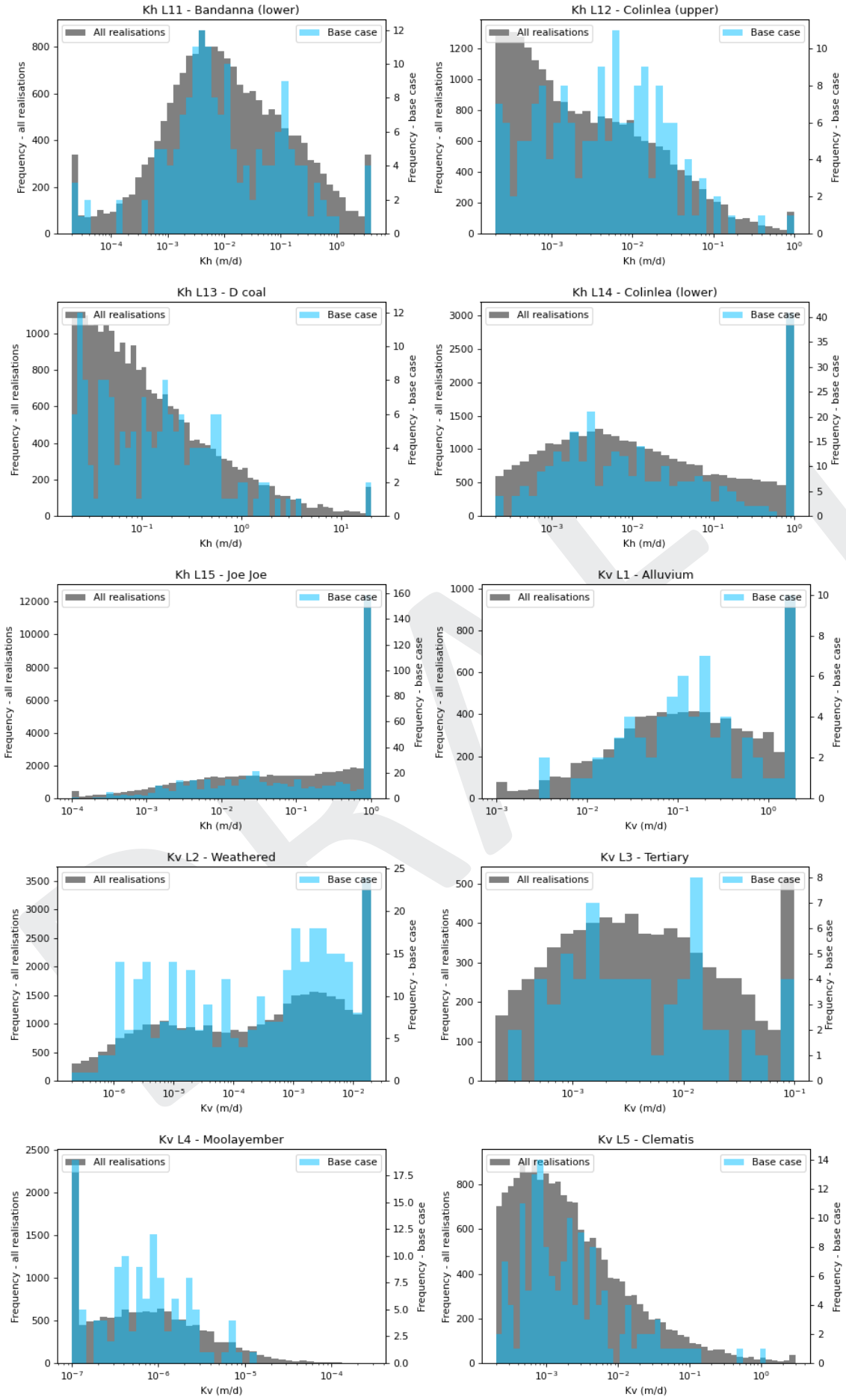
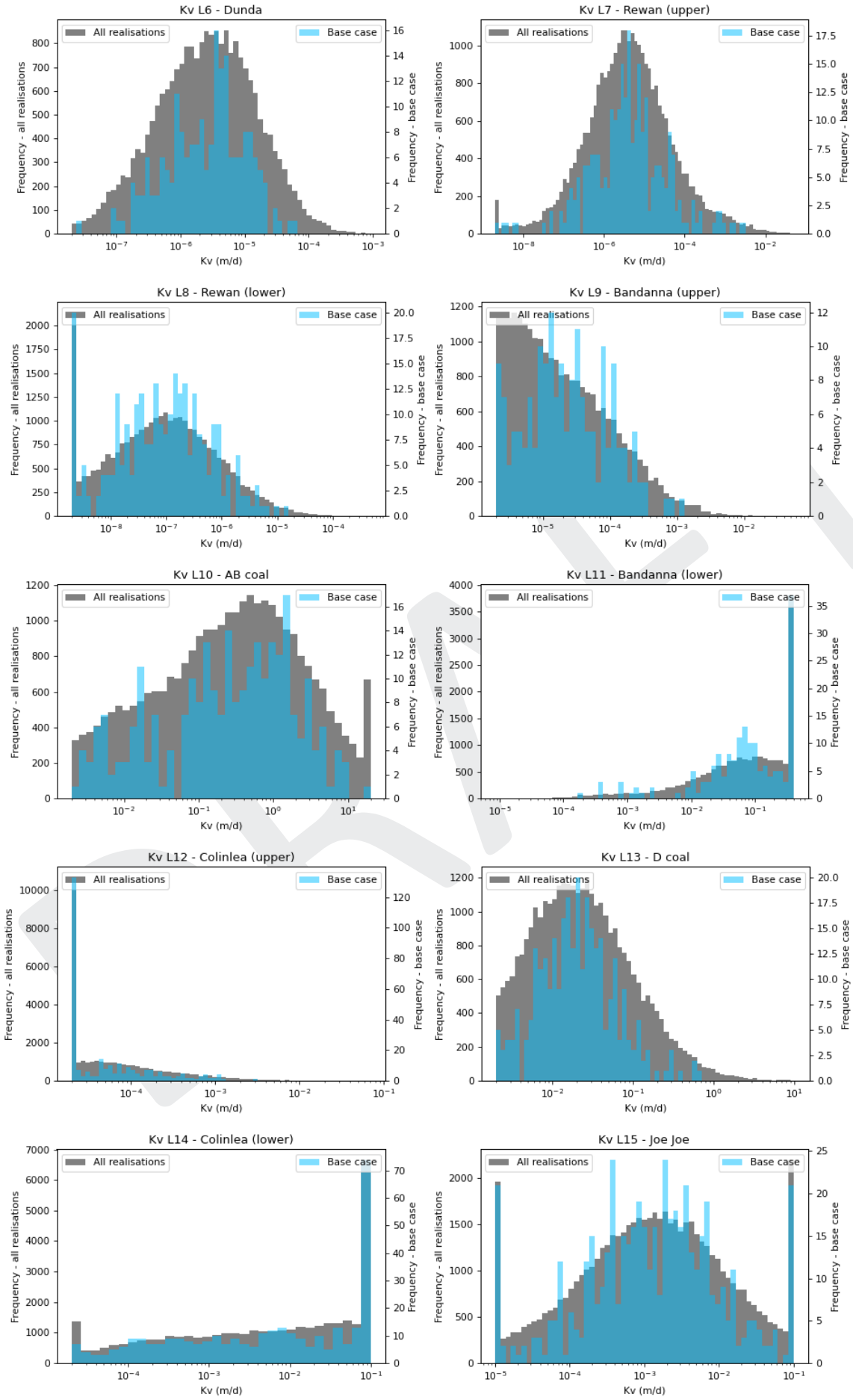
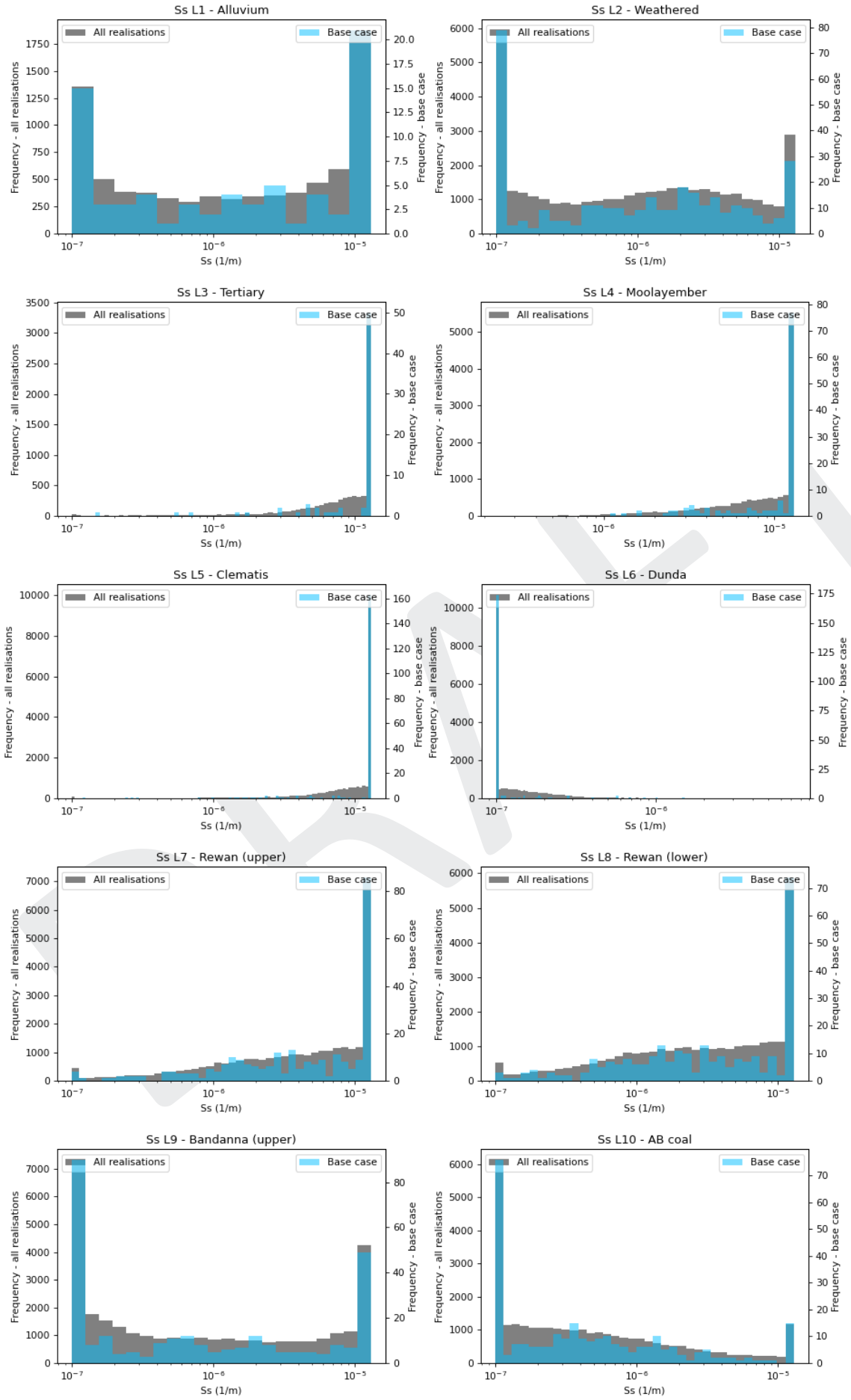
creating opportunities


Kh L1 - Alluvium
Kh L2 - Weathered
Kh L3 - Tertiary
Kh L4 - Moolayember
Kh L5 - Clematis
Kh L6 - Dunda
Kh L7 - Rewan (upper)
Kh L8 - Rewan (lower)
Kh L9 - Bandanna (upper)
Kh L10 - AB coal
All realisations
Base case
Frequency - all realisations
Frequency - base case
Kh (m/d)


Kh L11 - Bandanna (lower)
Kh L12 - Colinlea (upper)
Kh L13 - D coal
Kh L14 - Colinlea (lower)
Kh L15 - Joe Joe
Kv L1 - Alluvium
Kv L2 - Weathered
Kv L3 - Tertiary
Kv L4 - Moolayember
Kv L5 - Clematis
All realisations
Base case
Frequency - all realisations
Frequency - base case
Kh (m/d)
Kv (m/d)


Kv L6 - Dunda
Kv L7 - Rewan (upper)
Kv L8 - Rewan (lower)
Kv L9 - Bandanna (upper)
Kv L10 - AB coal
Kv L11 - Bandanna (lower)
Kv L12 - Colinlea (upper)
Kv L13 - D coal
Kv L14 - Colinlea (lower)
Kv L15 - Joe Joe
All realisations
Base case
Frequency - all realisations
Frequency - base case
Kv (m/d)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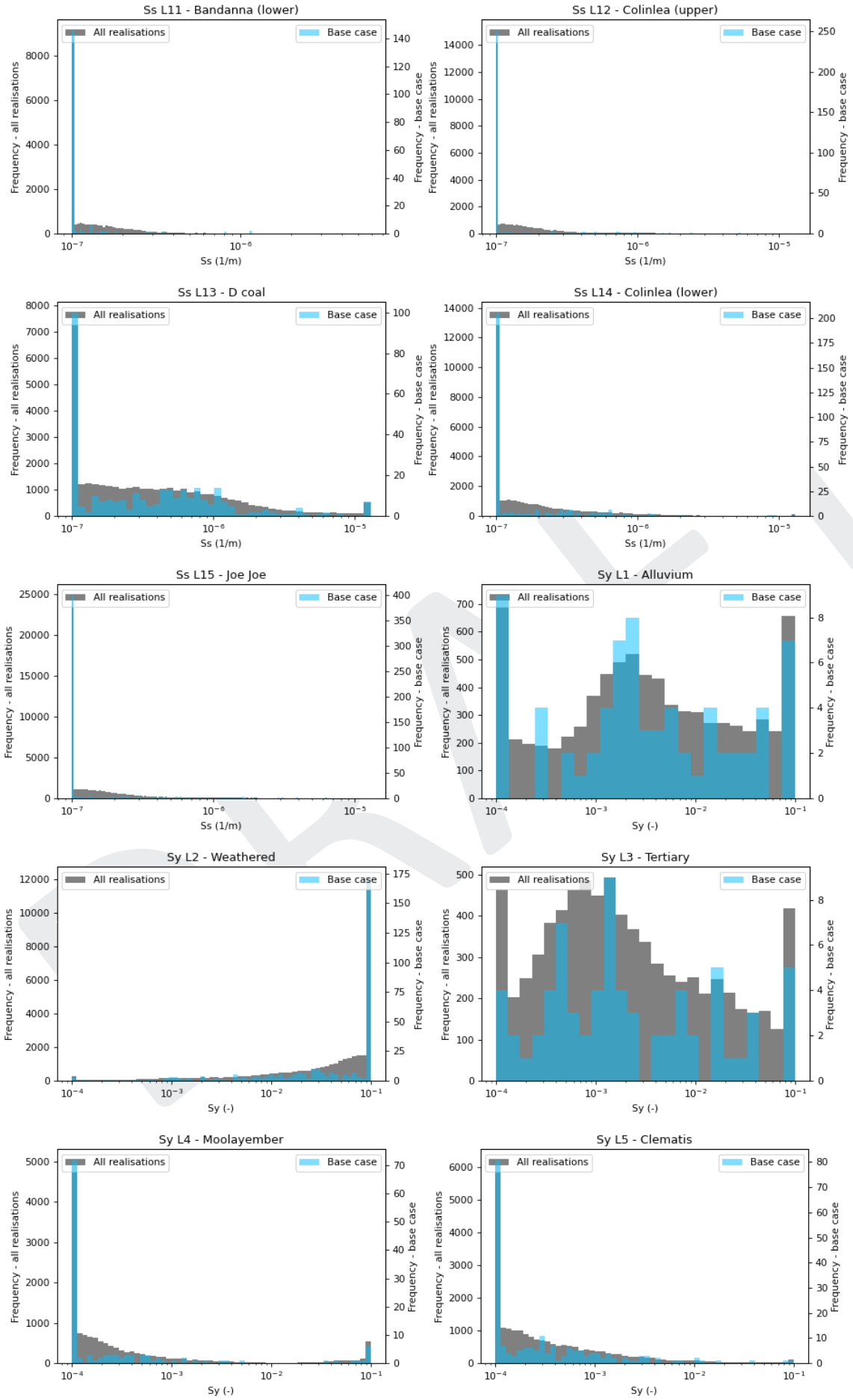
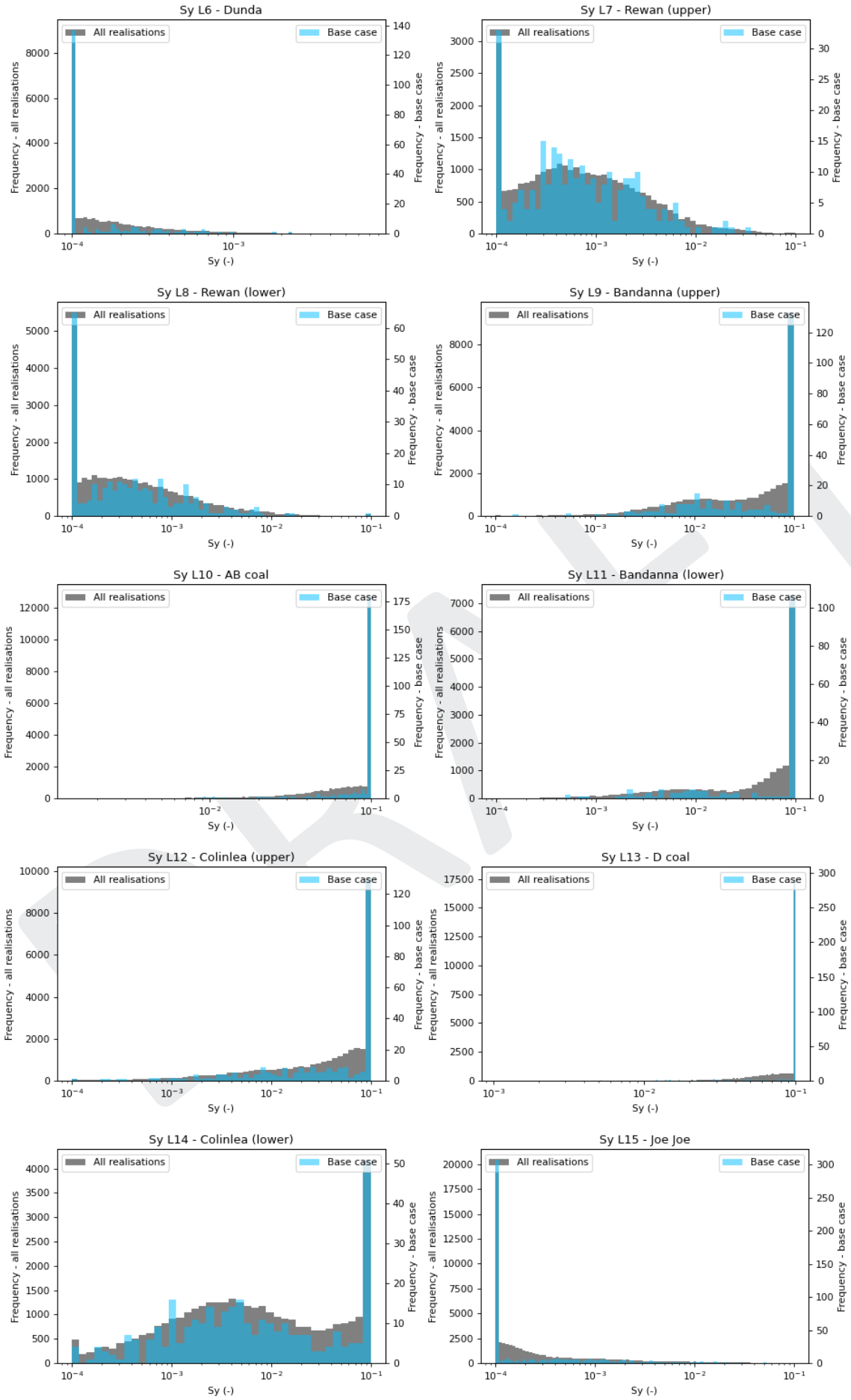
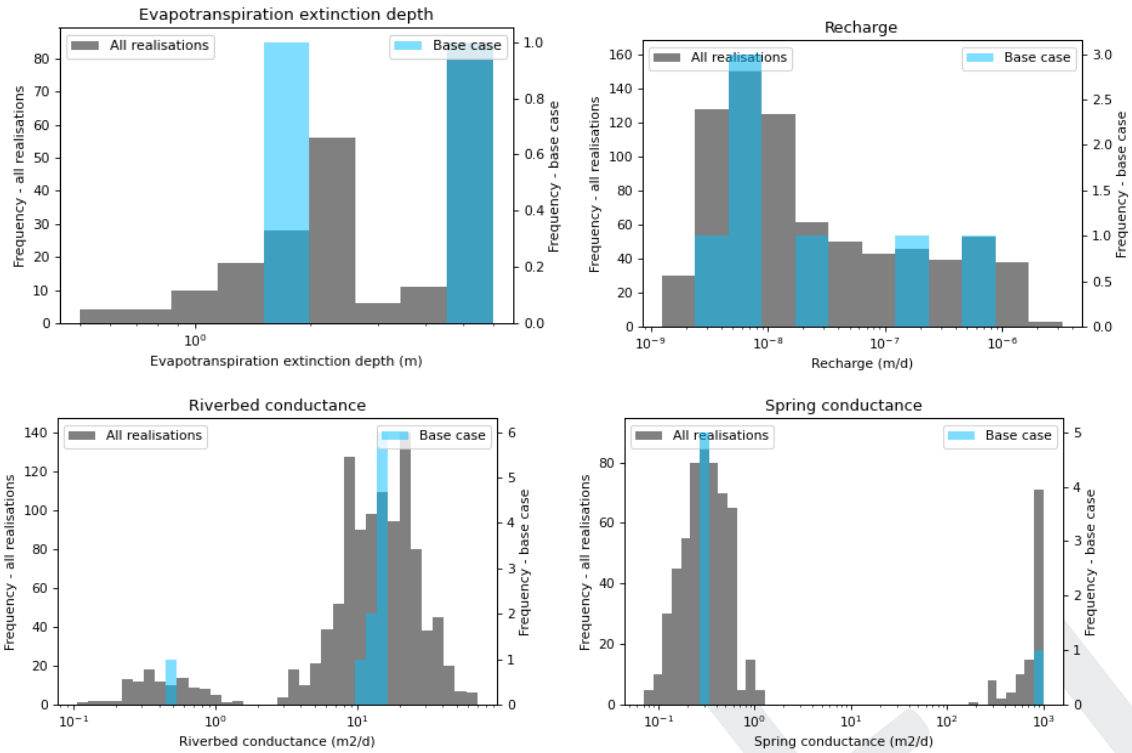
Ss L2 - Weathered
Ss L3 - Tertiary
Ss L4 - Moolayember
Ss L5 - Clematis
Ss L6 - Dunda
Ss L7 - Rewan (upper)
Ss L8 - Rewan (lower)
Ss L9 - Bandanna (upper)
Ss L10 - AB coal
All realisations
Base case
Frequency - all realisations
Frequency - base case
Ss (1/m)


Ss L11 - Bandanna (lower)
Ss L12 - Colinlea (upper)
Ss L13 - D coal
Ss L14 - Colinlea (lower)
Ss L15 - Joe Joe
Sy L1 - Alluvium
Sy L2 - Weathered
Sy L3 - Tertiary
Sy L4 - Moolayember
Sy L5 - Clematis
All realisations
Base case
Frequency - all realisations
Frequency - base case
Ss (1/m)
Sy (-)


Sy L6 - Dunda
Sy L7 - Rewan (upper)
Sy L8 - Rewan (lower)
Sy L9 - Bandanna (upper)
Sy L10 - AB coal
Sy L11 - Bandanna (lower)
Sy L12 - Colinlea (upper)
Sy L13 - D coal
Sy L14 - Colinlea (lower)
Sy L15 - Joe Joe
All realisations
Base case
Frequency - all realisations
Frequency - base case
Sy (-)


Evapotranspiration extinction depth
All realisations
Base case
Frequency - all realisations
Frequency - base case
Evapotranspiration extinction depth (m)
Recharge
Recharge (m/d)
Riverbed conductance
Riverbed conductance (m2/d)
Spring conductance
Spring conductance (m2/d)

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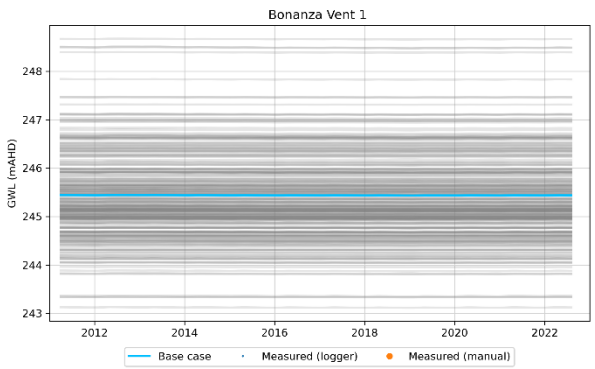
Appendix C

Hydrographs: history-matching

EMM
creating opportunities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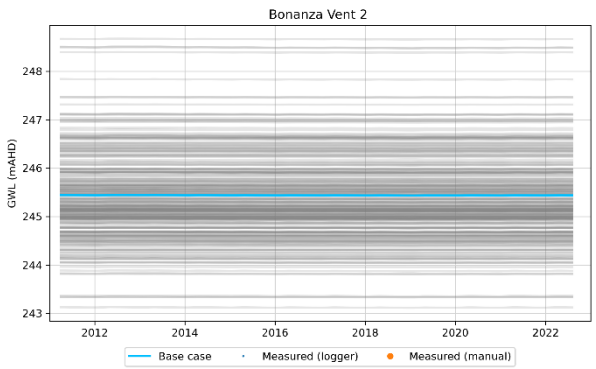
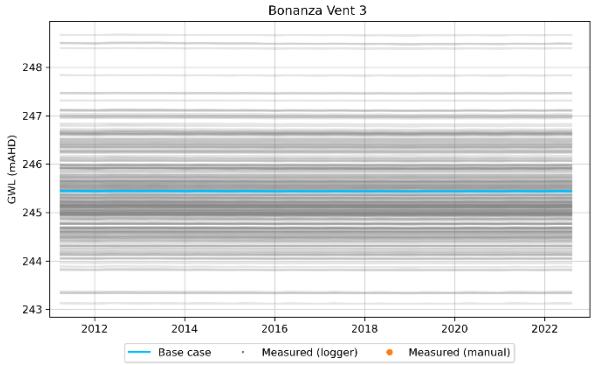
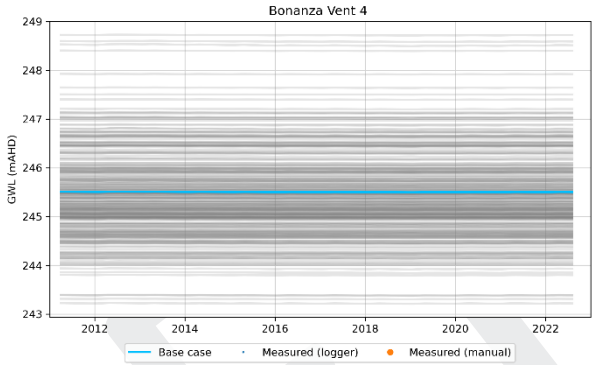
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


Bonanza Vent 2
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


Bonanza Vent 3
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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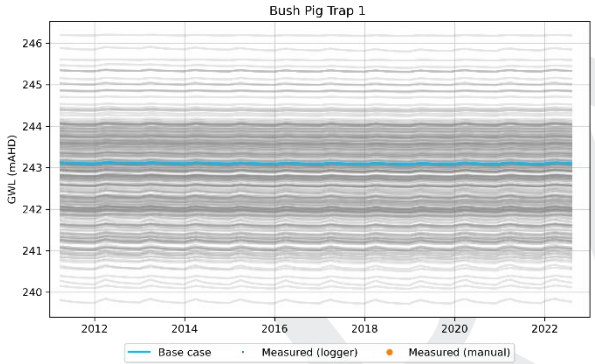
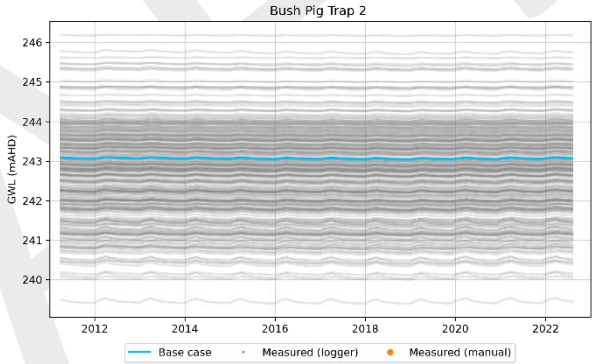

Bush Pig Trap 1
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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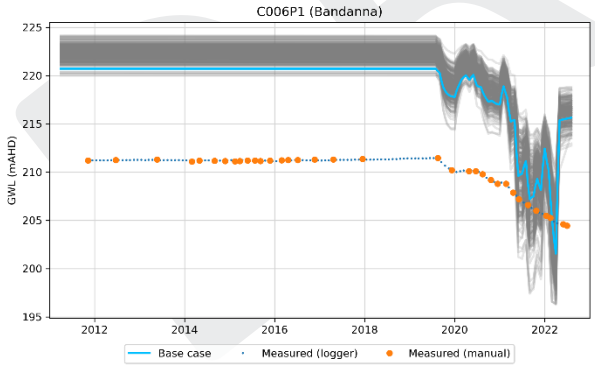
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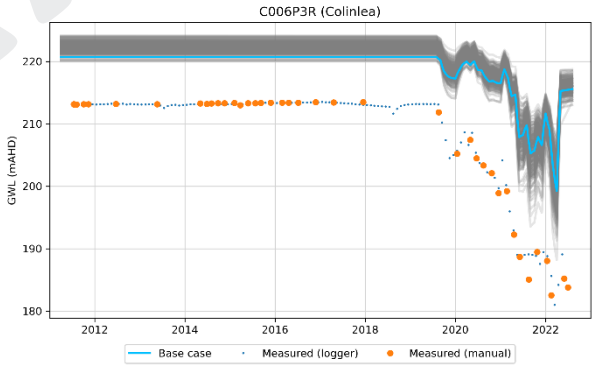
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GWL (mAHD)
Base case
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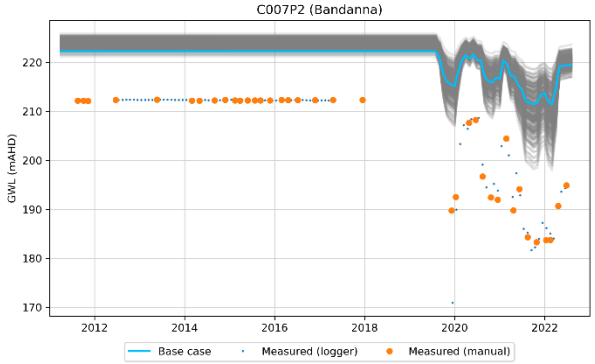
Measured (manual)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Measured (logger)
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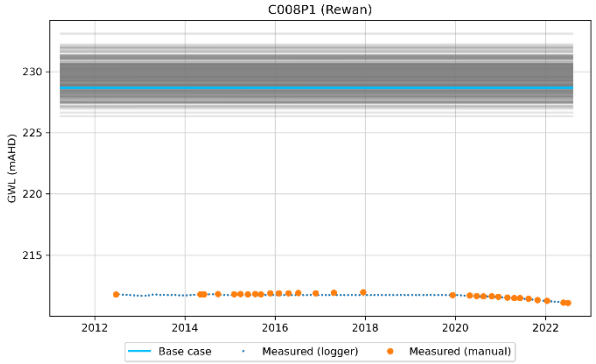
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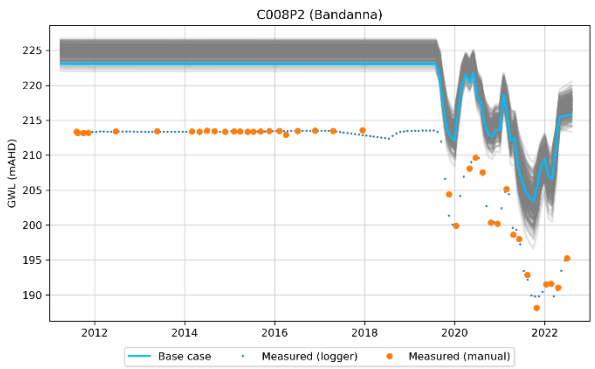
Measured (manual)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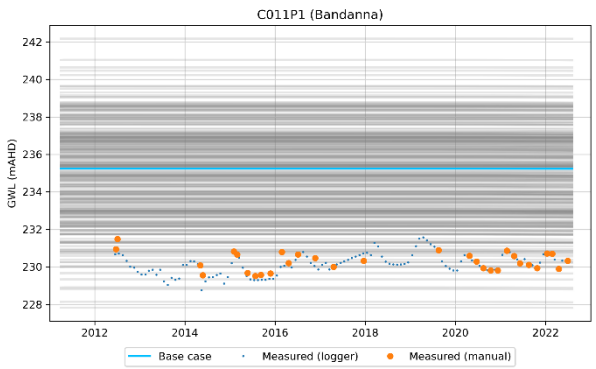
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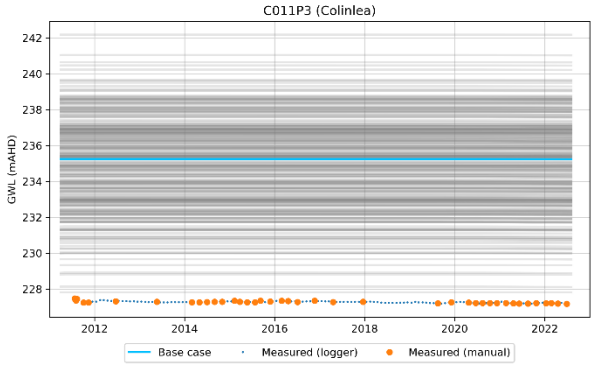
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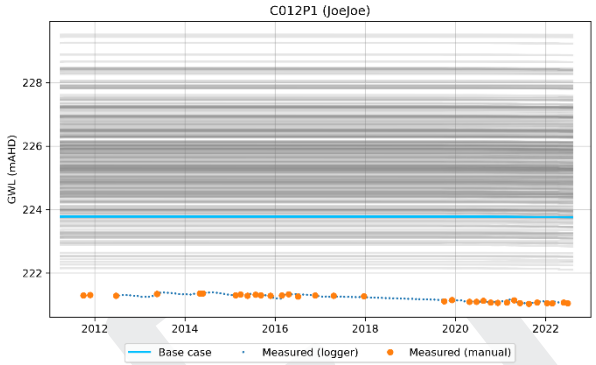
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Base case
Measured (logger)
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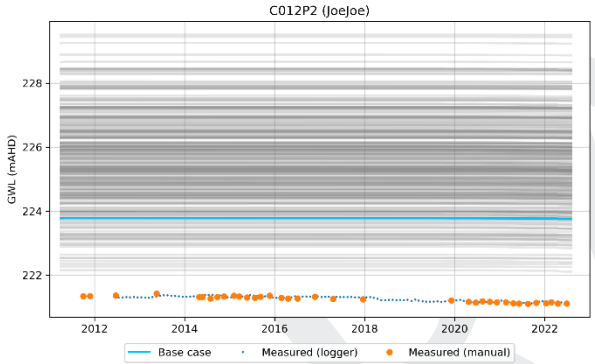
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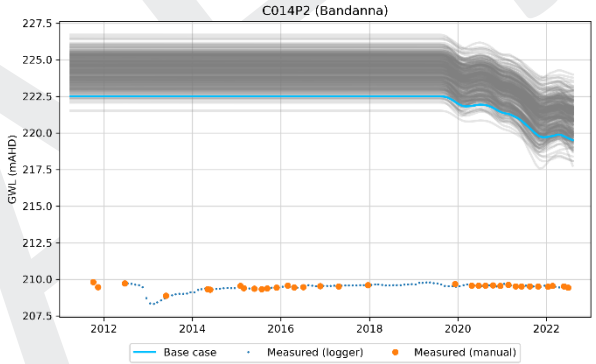
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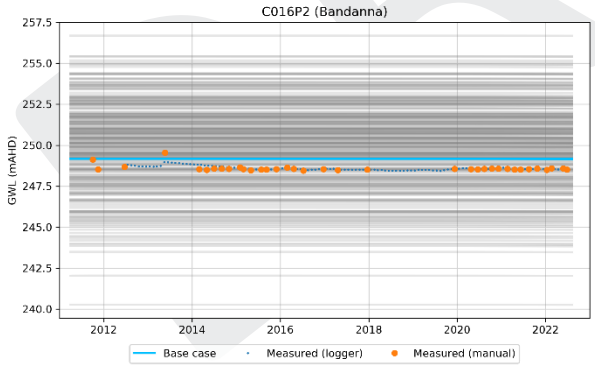
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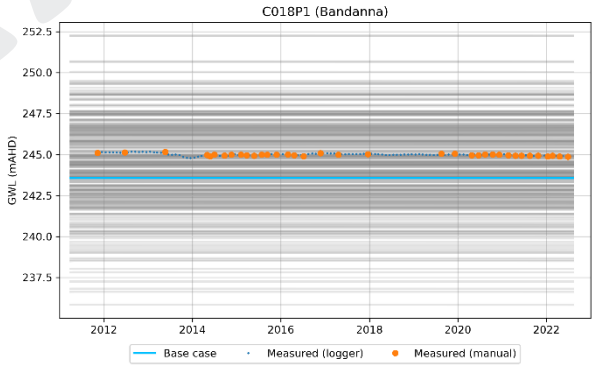
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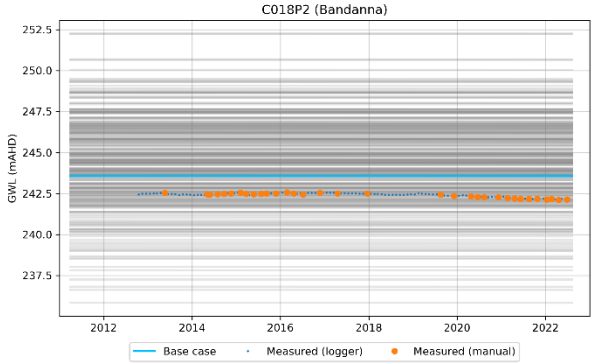
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Base case
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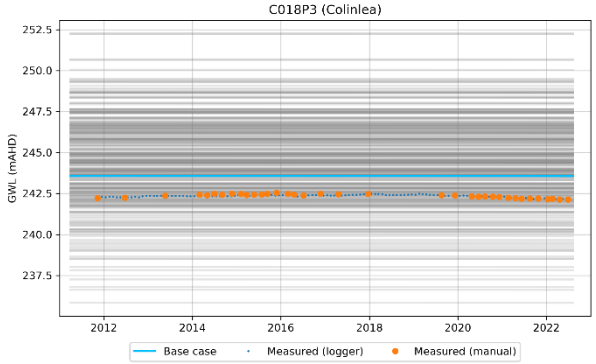
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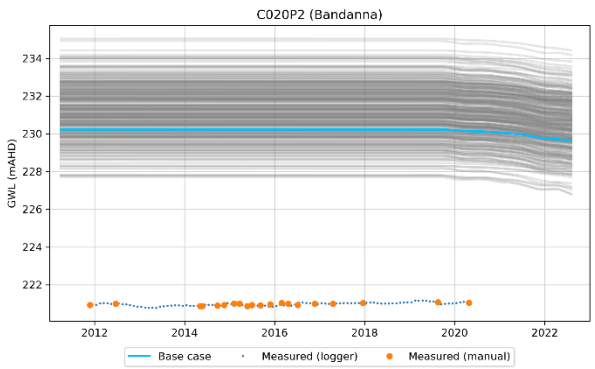
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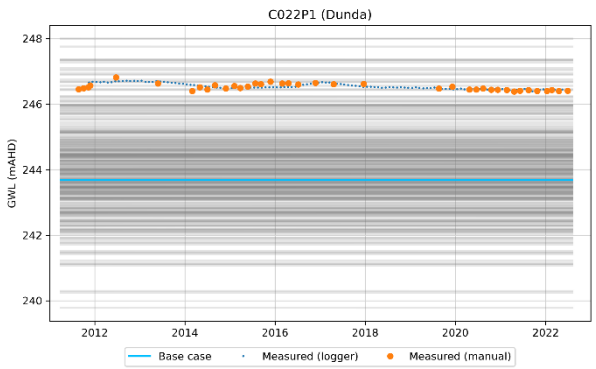
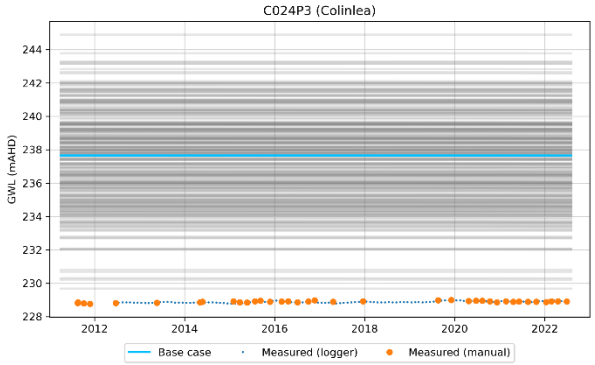
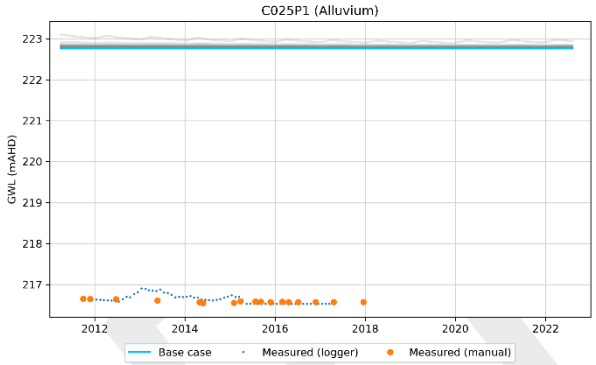
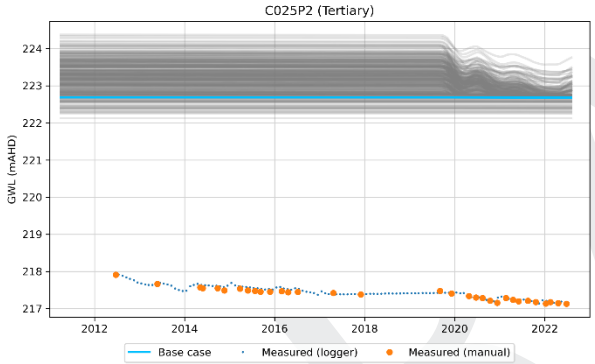
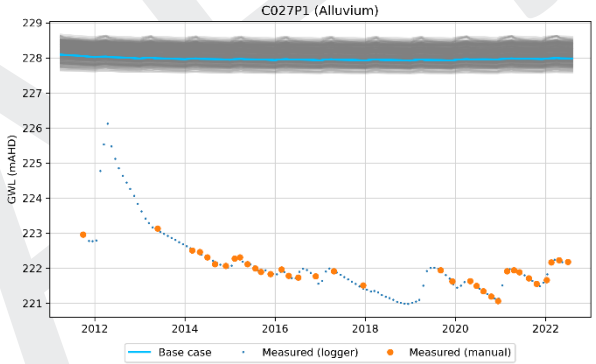
Measured (logger)
Measured (manual)

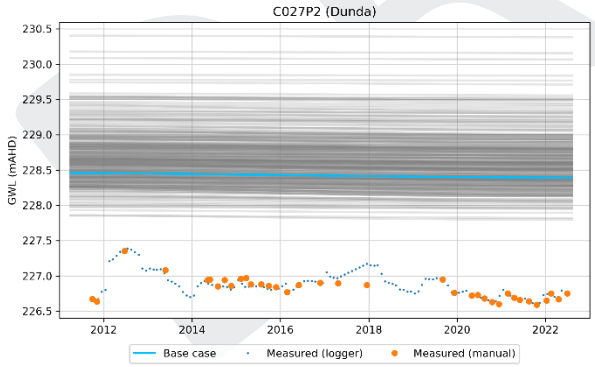

C022P1 (Dunda)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

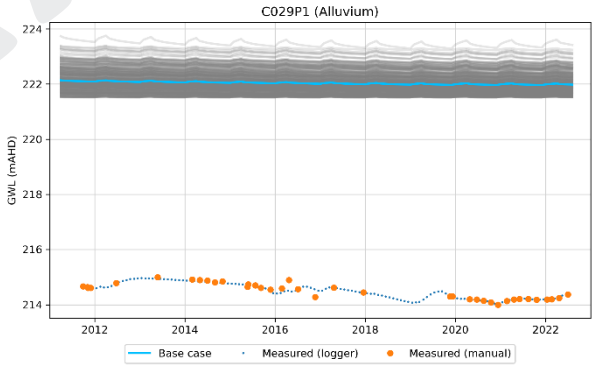

C024P3 (Colinlea)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

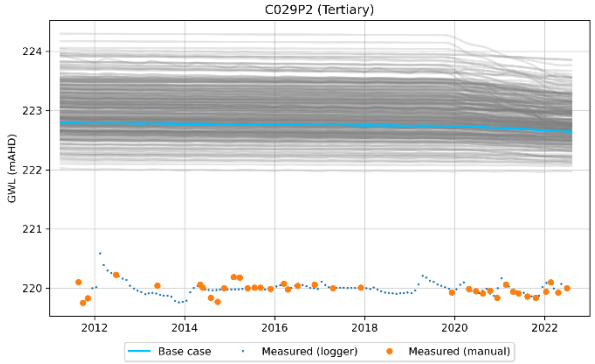

C025P1 (Alluvium)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

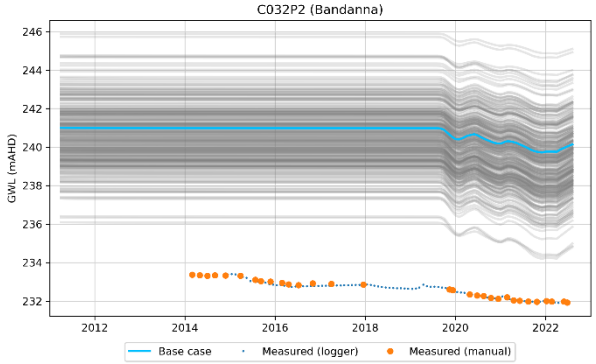

C025P2 (Tertiary)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

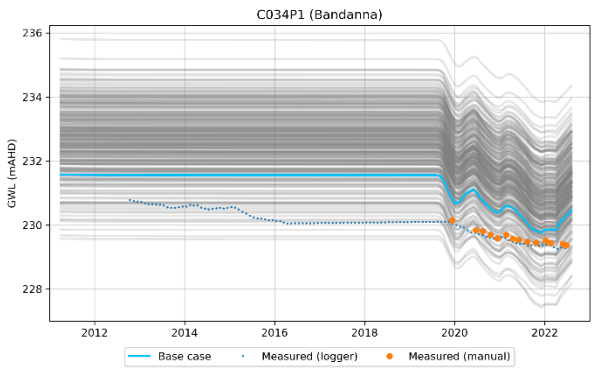

C027P1 (Alluvium)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

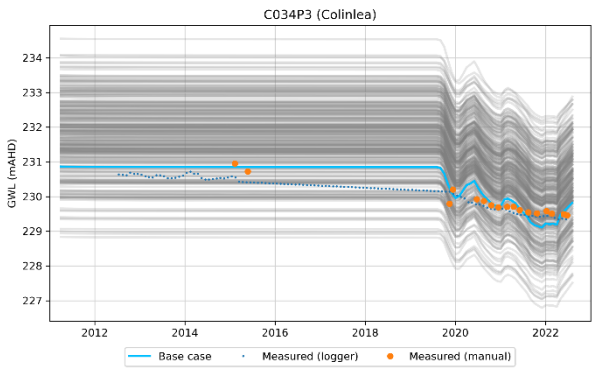

C027P2 (Dunda)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

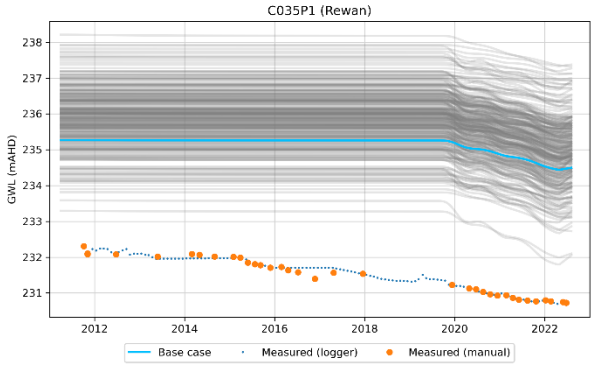

C029P1 (Alluvium)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

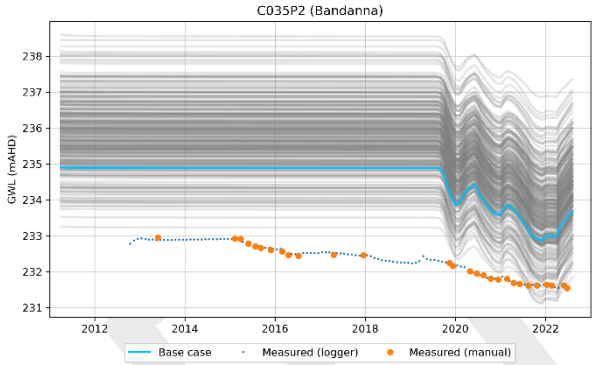

C029P2 (Tertiary)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

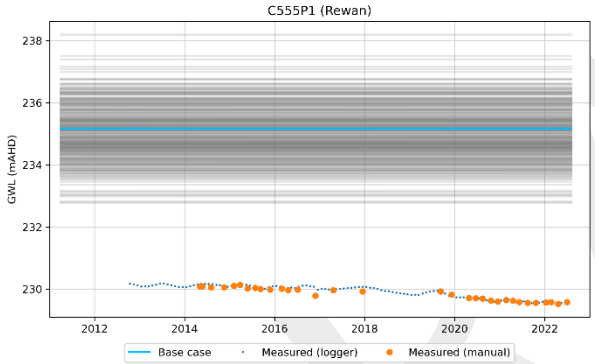

C032P2 (Bandanna)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

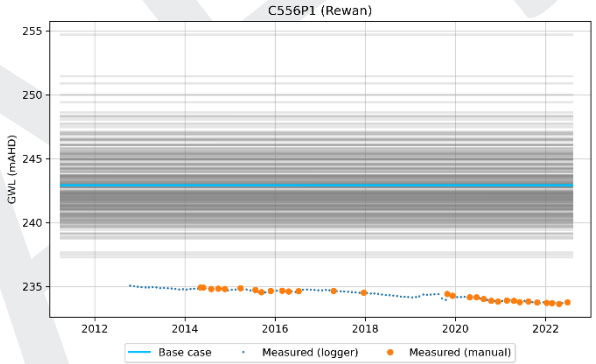

C034P1 (Bandanna)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

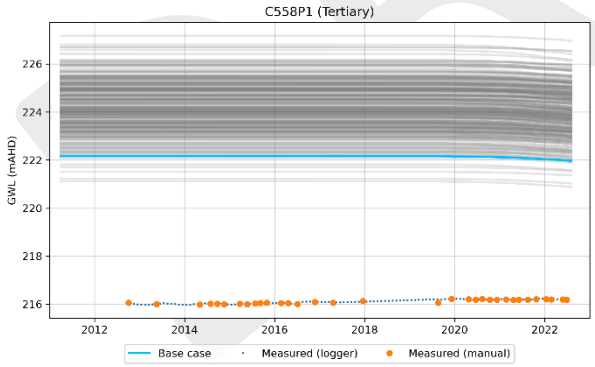

C034P3 (Colinlea)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

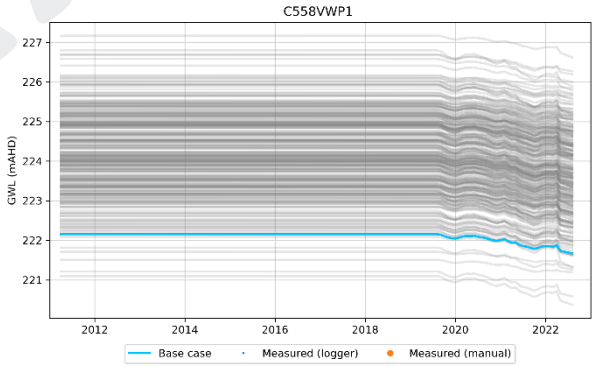

C035P1 (Rewan)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

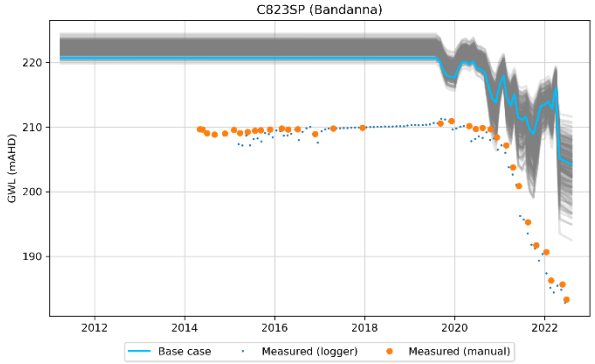

C035P2 (Bandanna)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

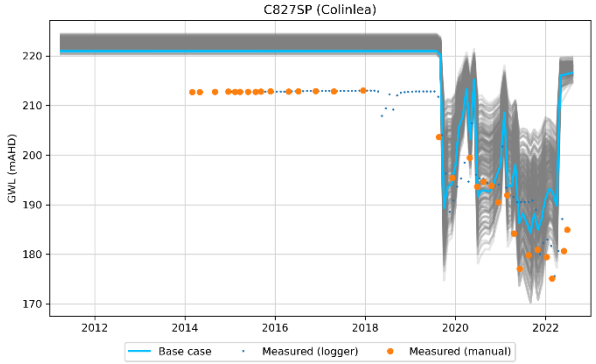

C555P1 (Rewan)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

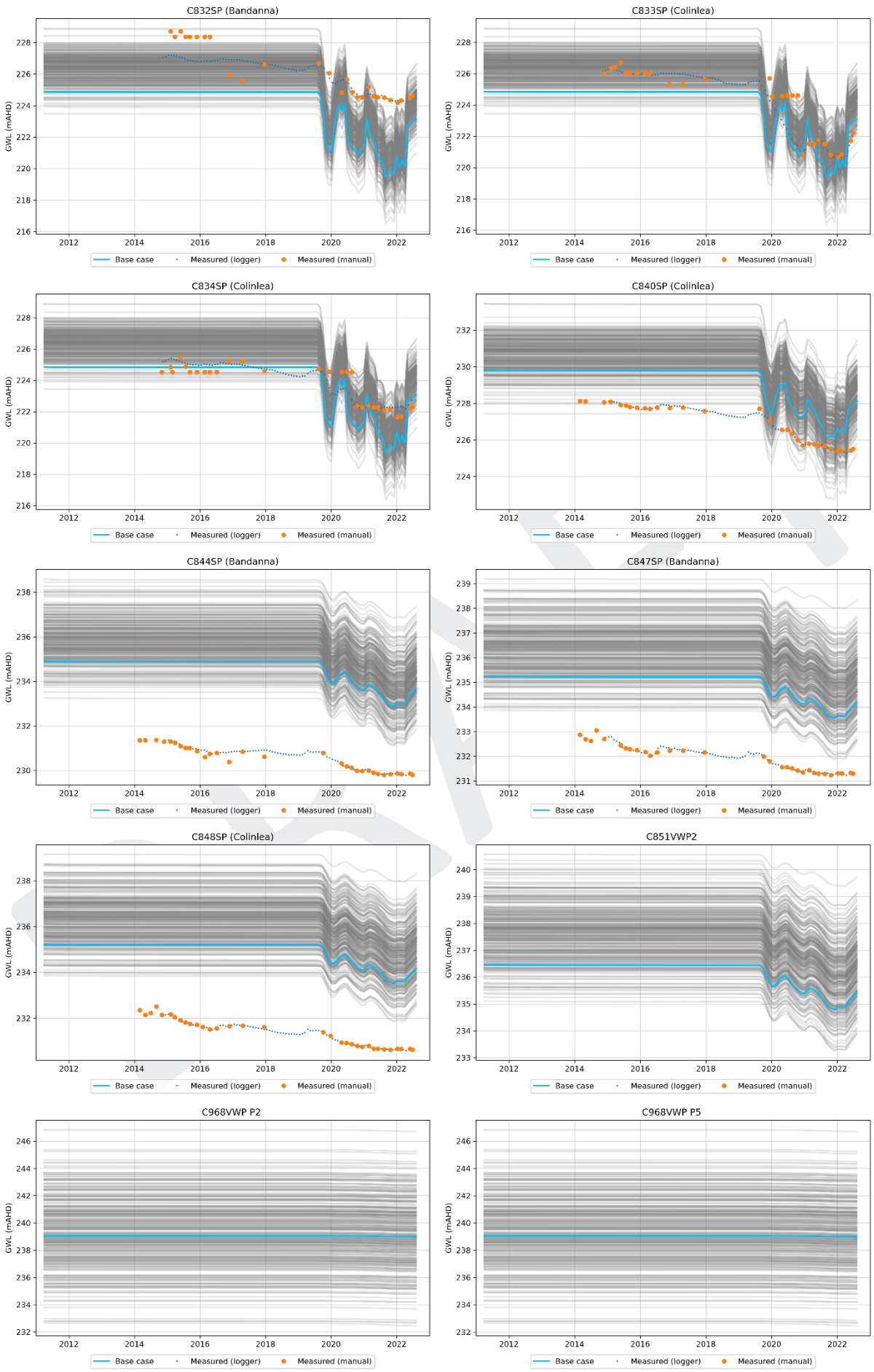

C556P1 (Rewan)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

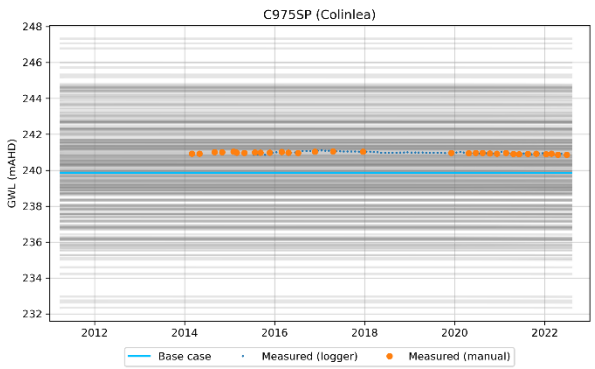

C558P1 (Tertiary)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

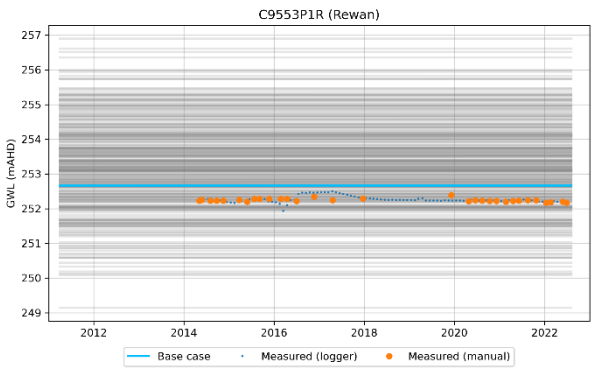

C558VWP1
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

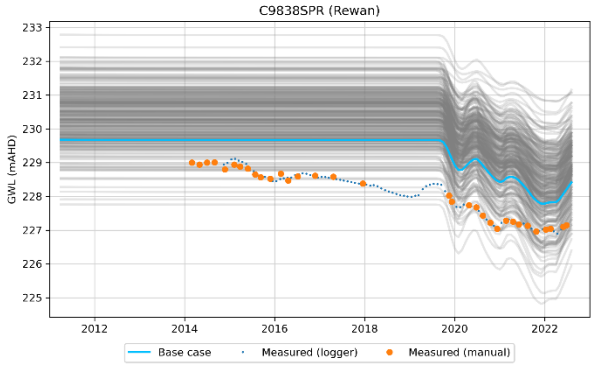

C823SP (Bandanna)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

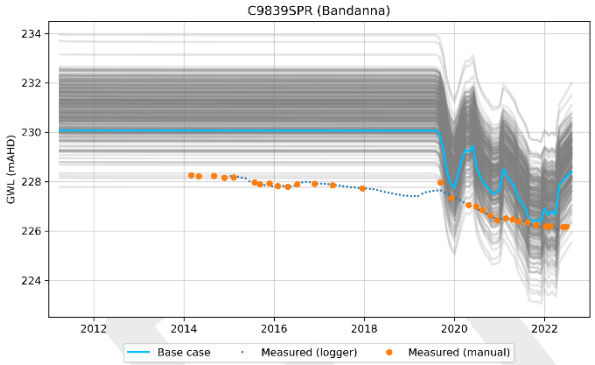

C827SP (Colinlea)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

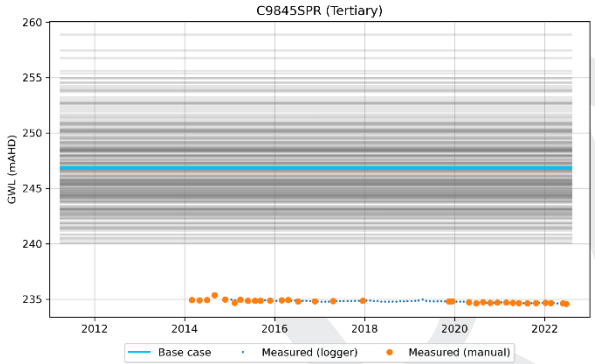

C832SP (Bandanna)
C833SP (Colinlea)
C834SP (Colinlea)
C840SP (Colinlea)
C844SP (Bandanna)
C847SP (Bandanna)
C848SP (Colinlea)
C851VWP2
C968VWP P2
C968VWP P5
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

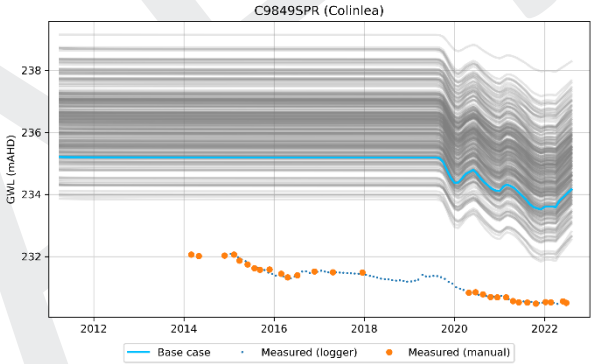

C975SP (Colinlea)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

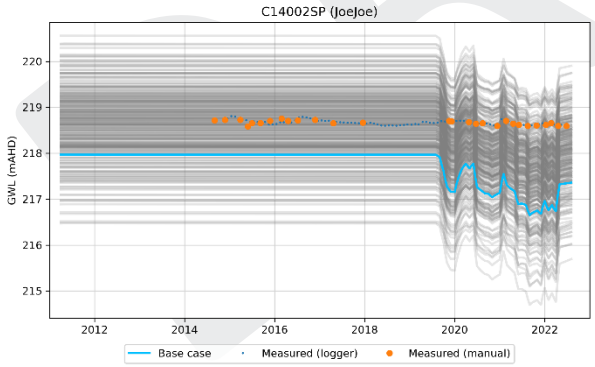

C9553P1R (Rewan)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

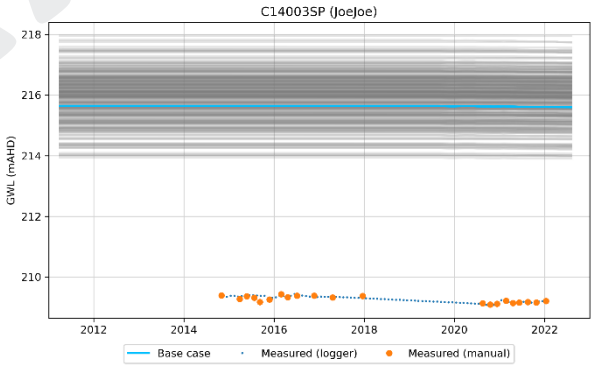

C9838SPR (Rewan)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

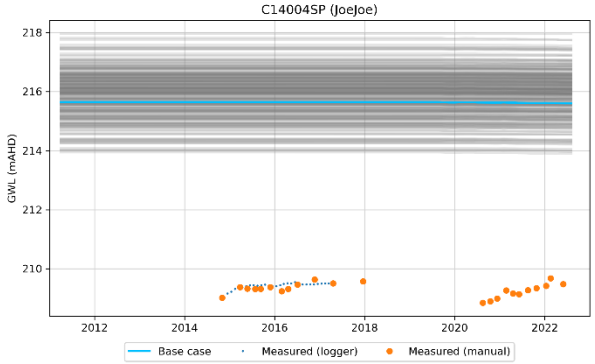

C9839SPR (Bandanna)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

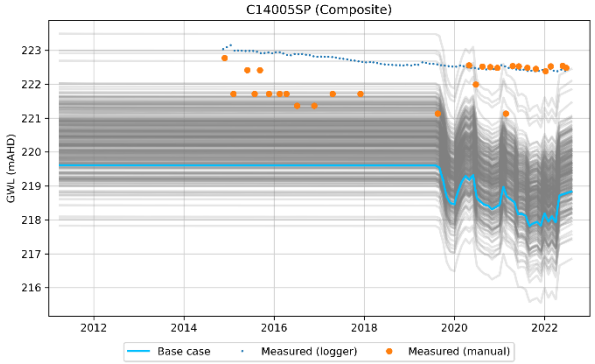

C9845SPR (Tertiary)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

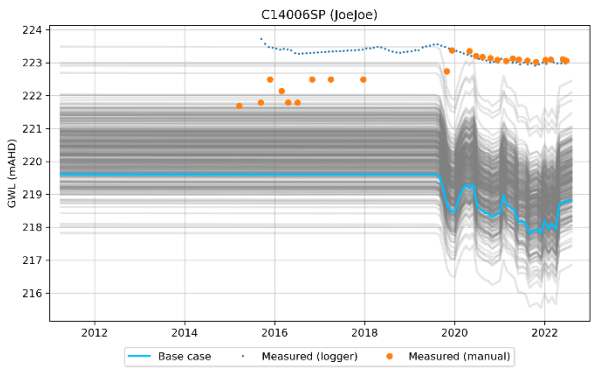

C9849SPR (Colinlea)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

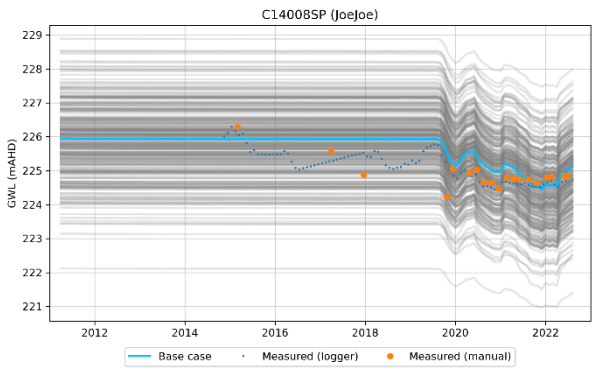

C14002SP (JoeJoe)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

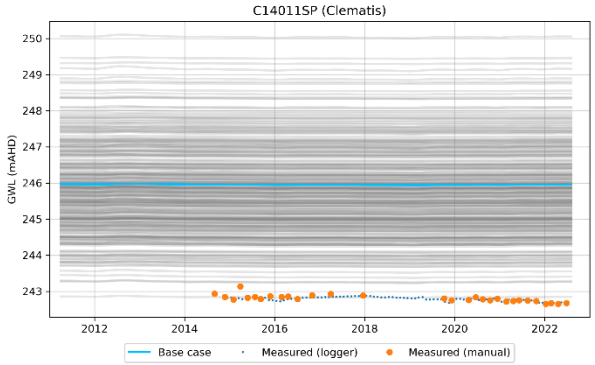

C14003SP (JoeJoe)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

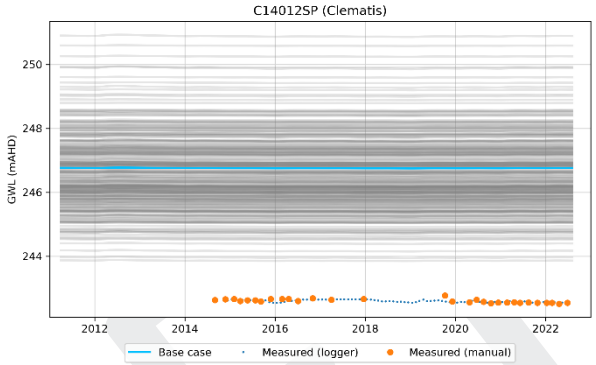

C14004SP (JoeJoe)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

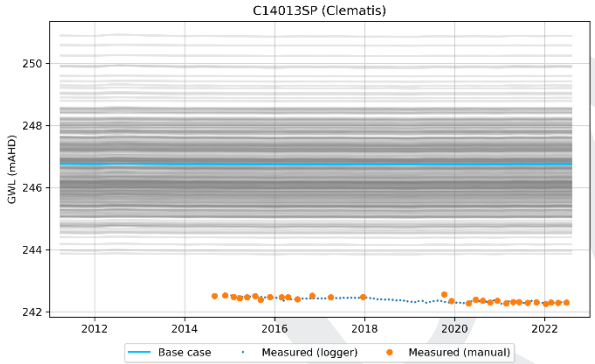

C14005SP (Composite)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

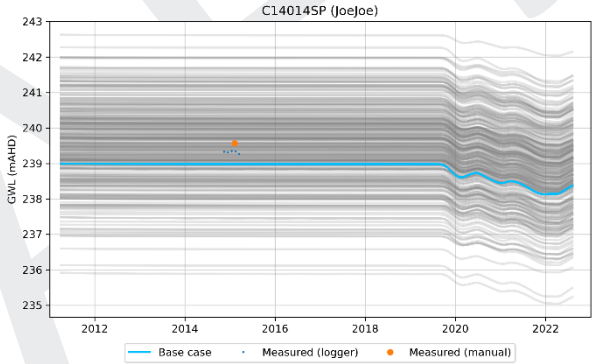

C14006SP (JoeJoe)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

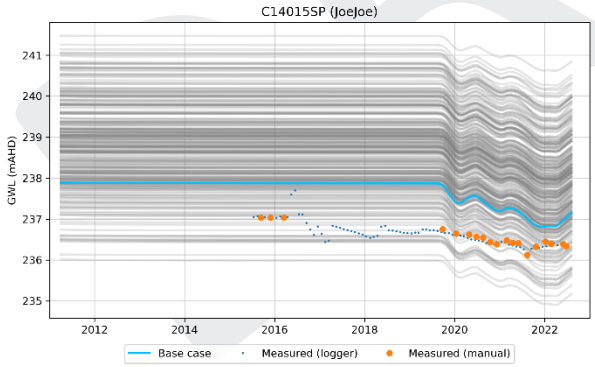

C14008SP (JoeJoe)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

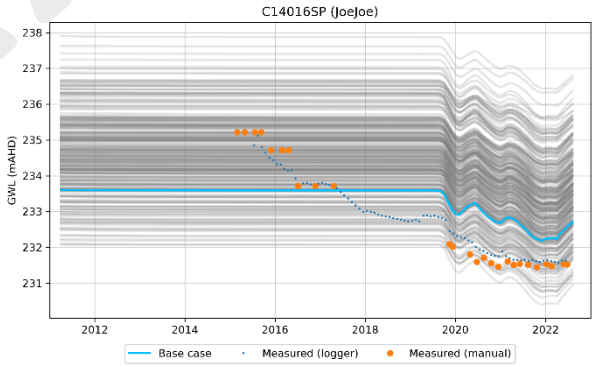

C14011SP (Clematis)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

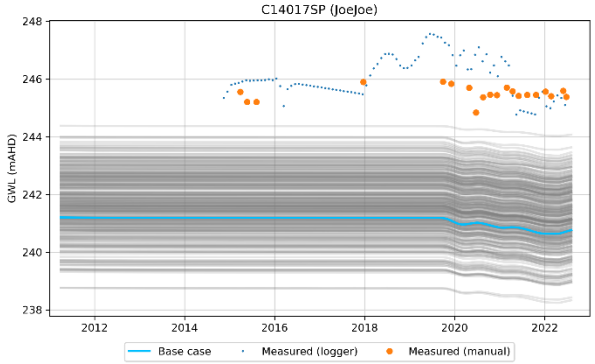

C14012SP (Clematis)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

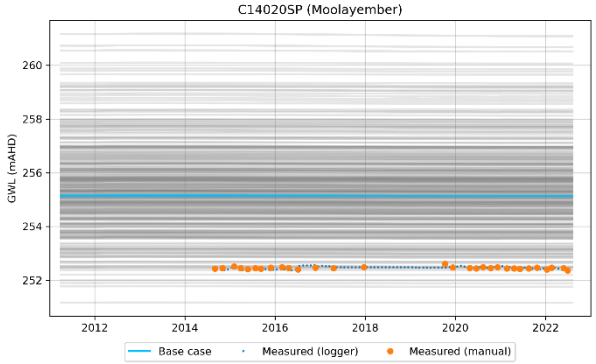

C14013SP (Clematis)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

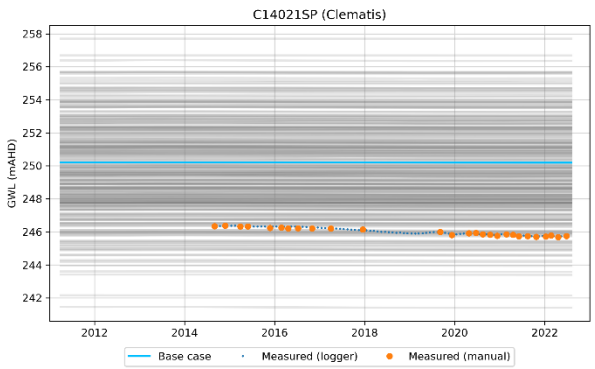

C14014SP (JoeJoe)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

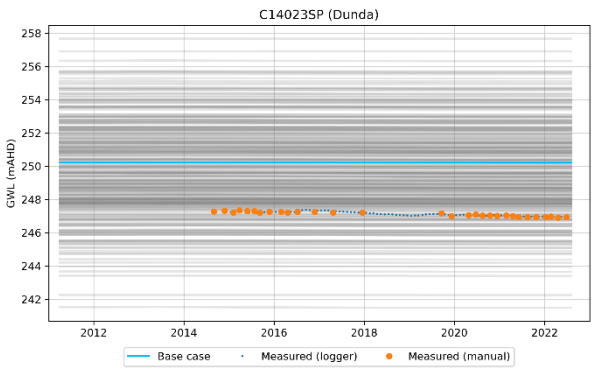

C14015SP (JoeJoe)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

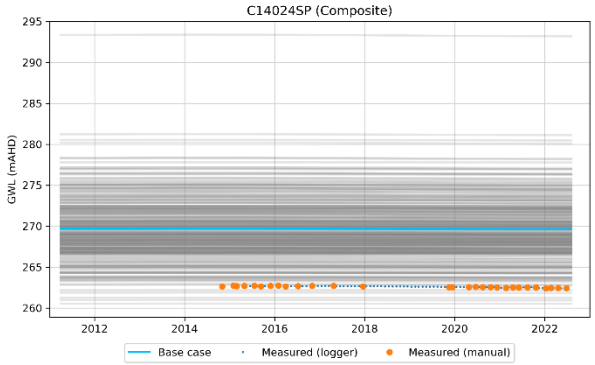

C14016SP (JoeJoe)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

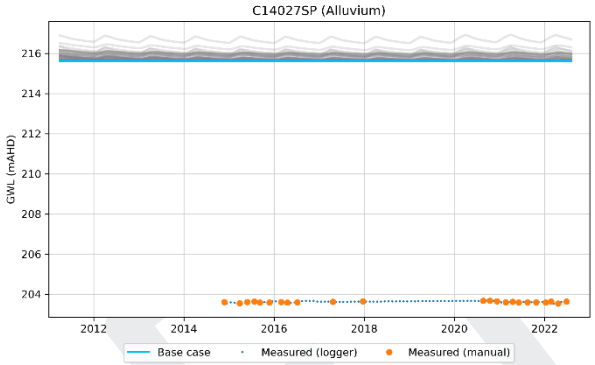

C14017SP (JoeJoe)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

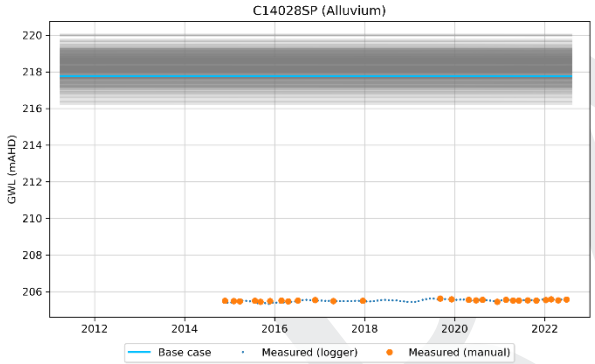

C14020SP (Moolayember)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

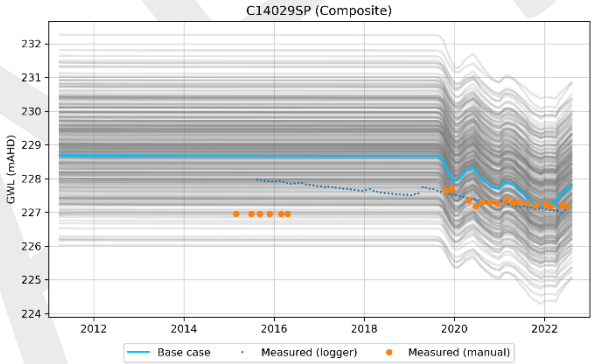

C14021SP (Clematis)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

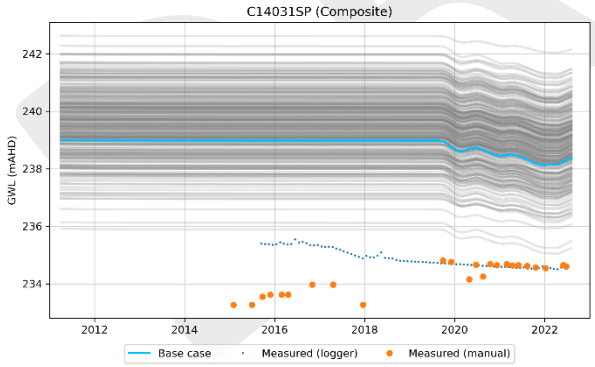

C14023SP (Dunda)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

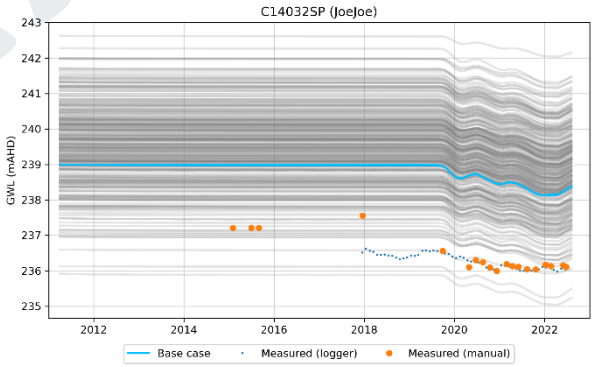

C14024SP (Composite)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


C14027SP (Alluvium)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


C14028SP (Alluvium)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


C14029SP (Composite)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


C14031SP (Composite)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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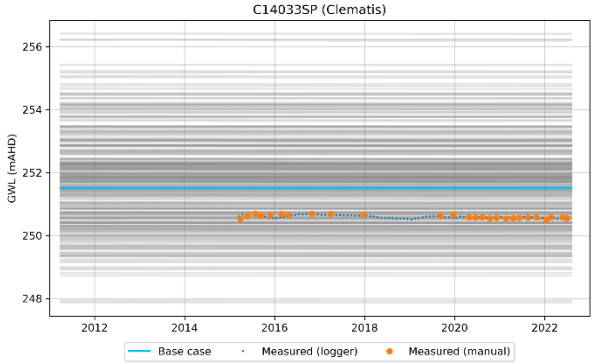
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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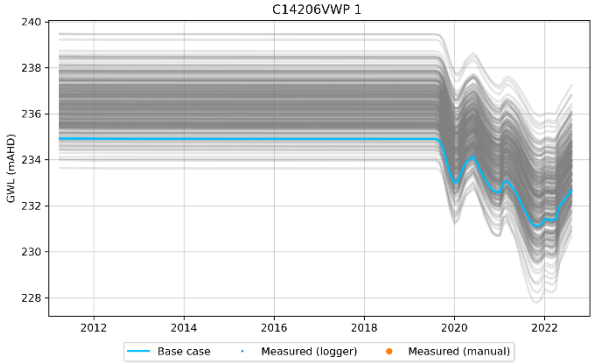
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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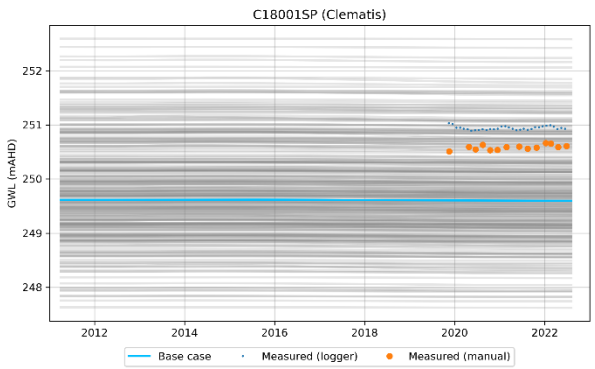
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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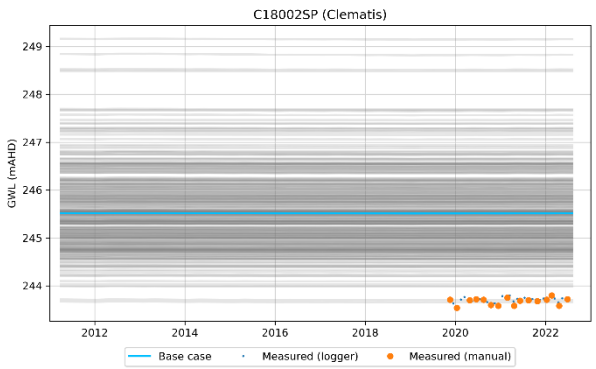
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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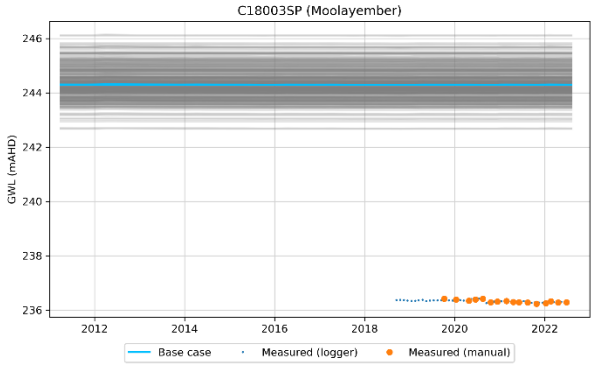
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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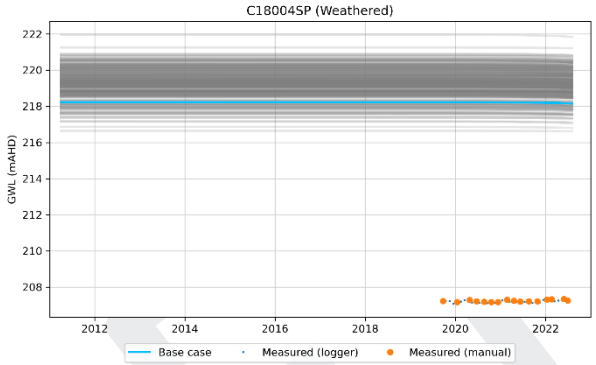
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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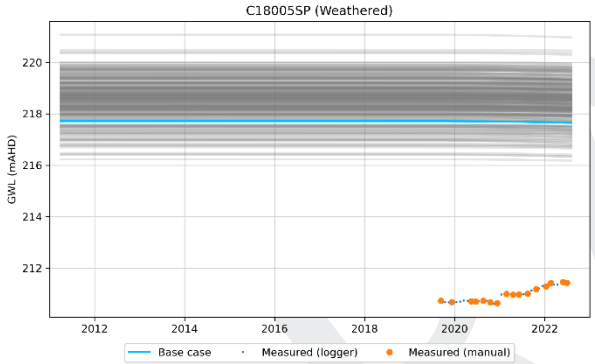
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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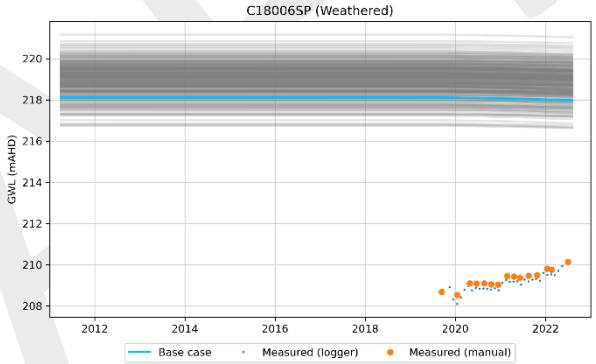
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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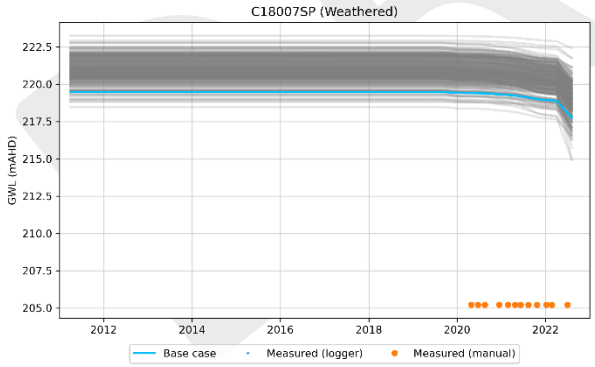
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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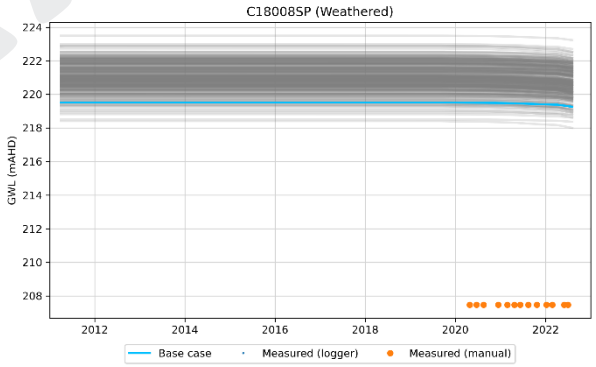
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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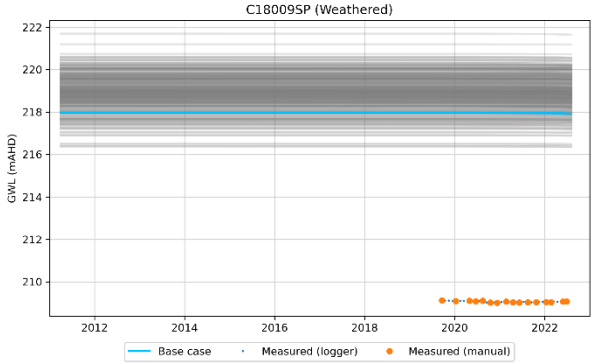
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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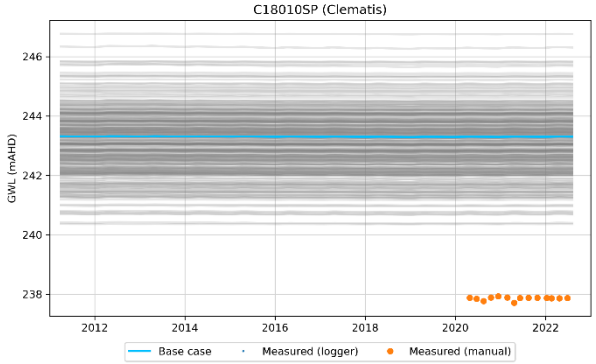
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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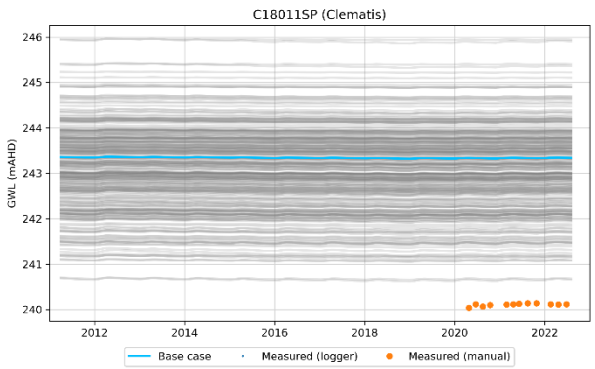
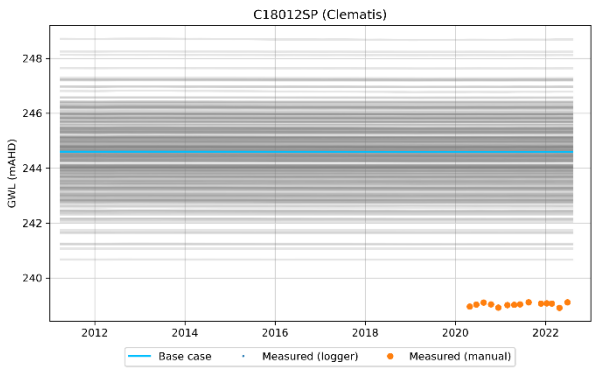
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


C18011SP (Clematis)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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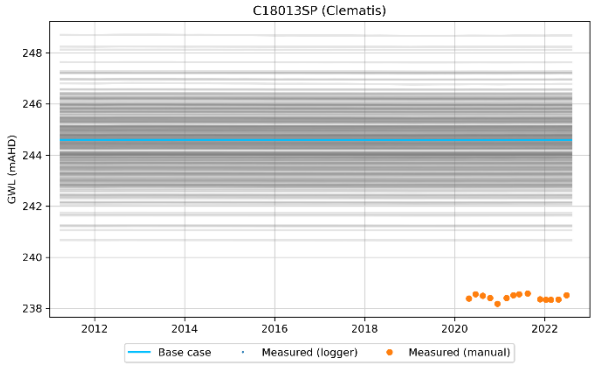
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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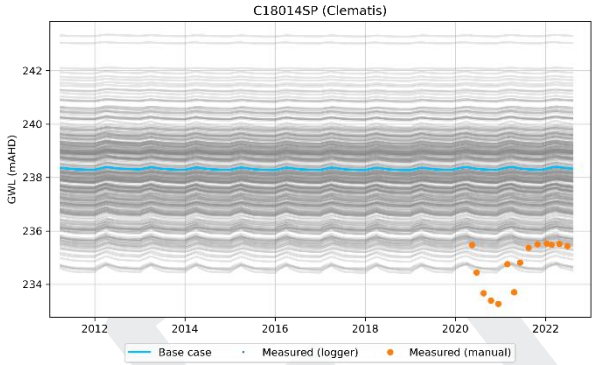
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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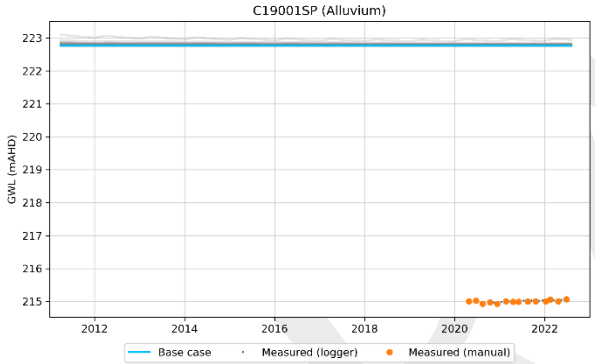
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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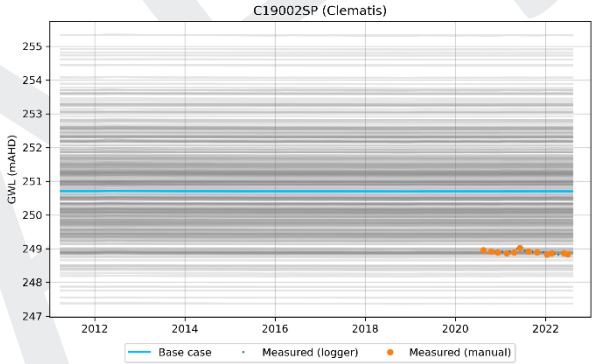
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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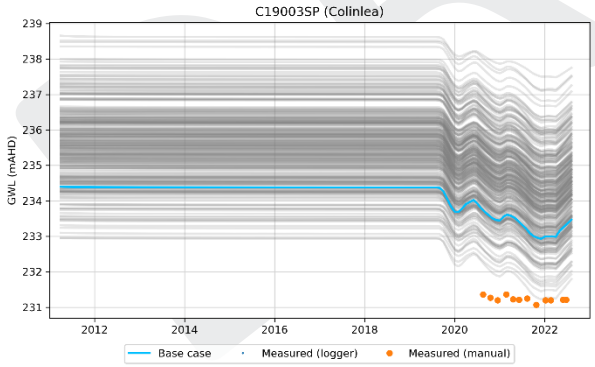
Base case
Measured (logger)
Measured (manual)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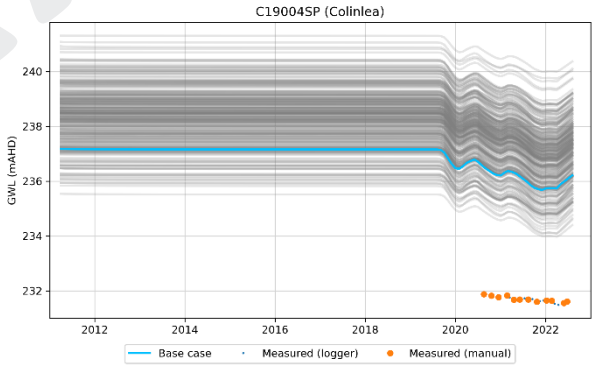
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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GWL (mAHD)
Base case
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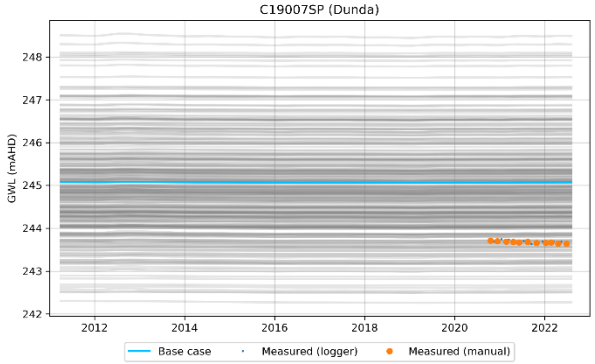
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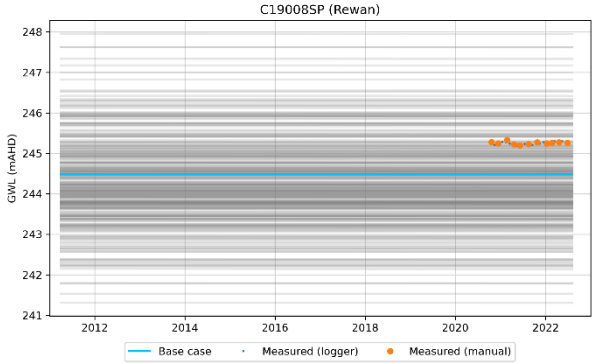
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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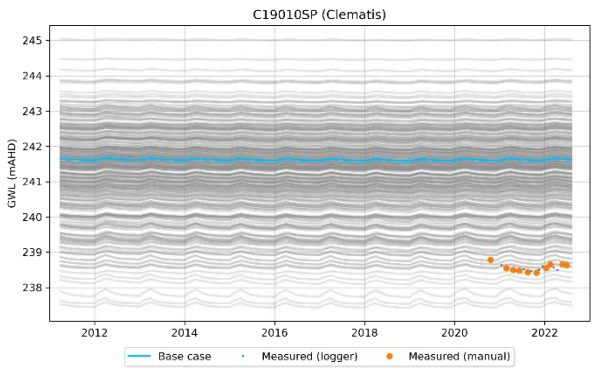
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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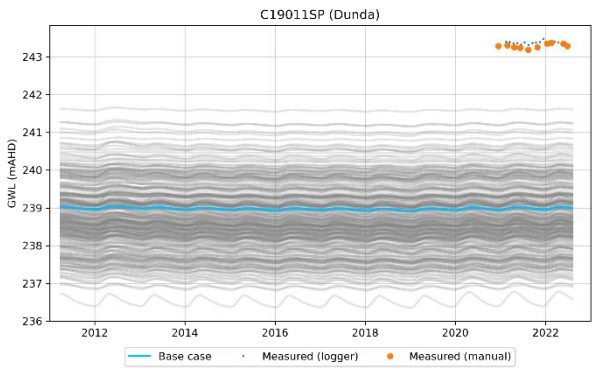
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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GWL (mAHD)
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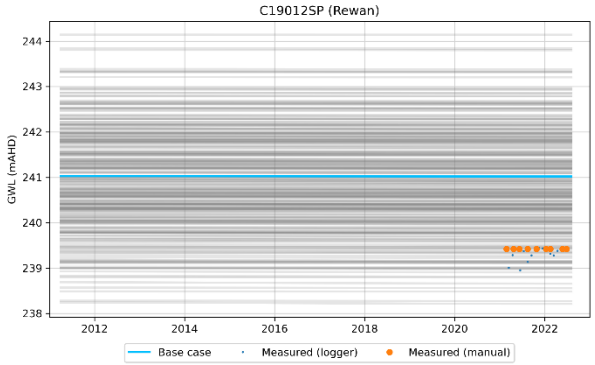
Measured (logger)
Measured (manual)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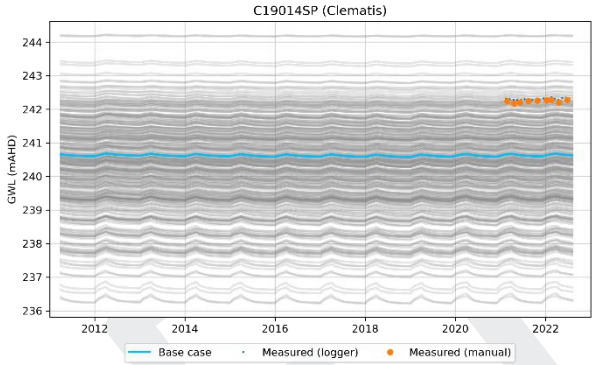
Measured (manual)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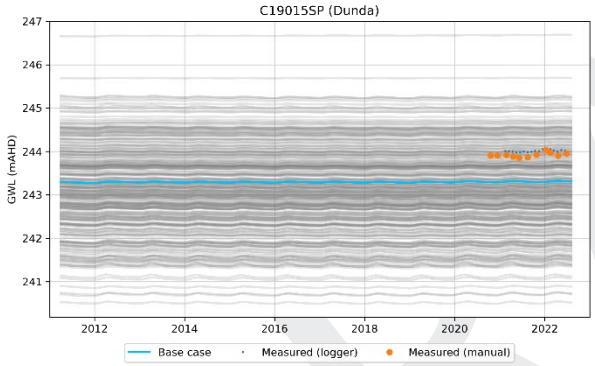
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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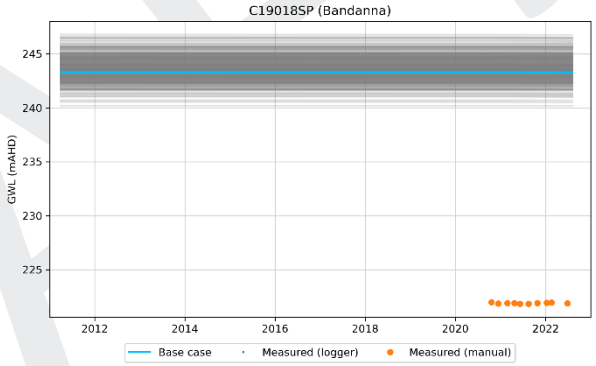
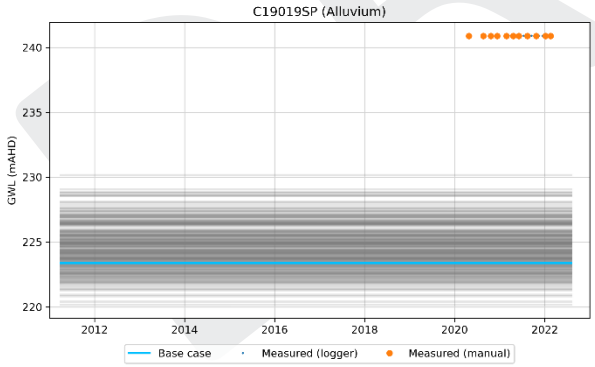
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


C19018SP (Bandanna)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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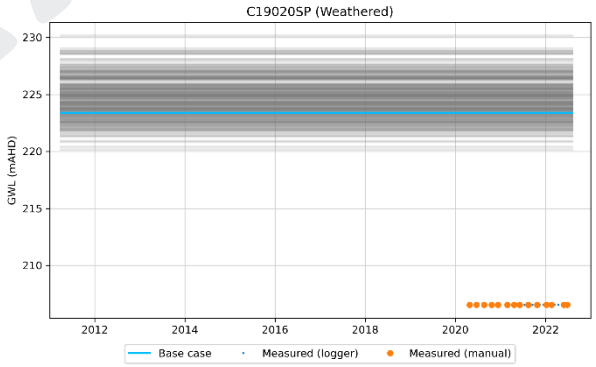
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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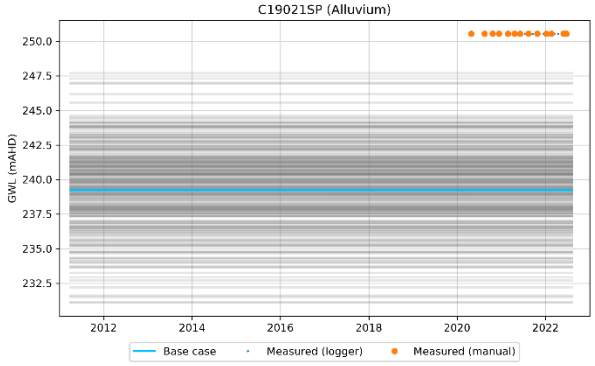
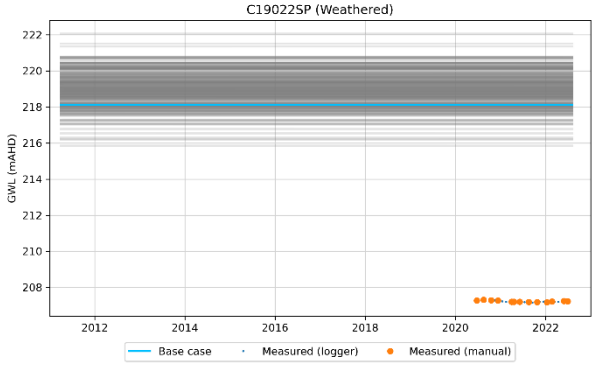
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


C19021SP (Alluvium)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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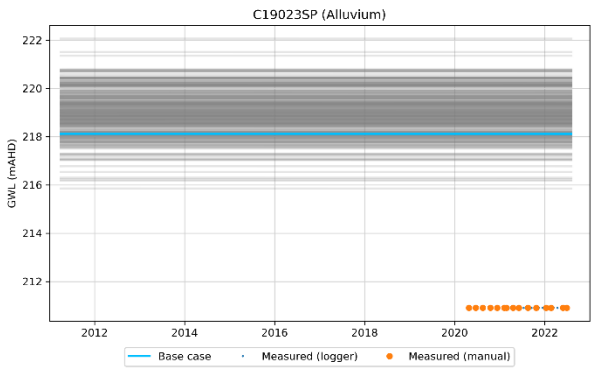
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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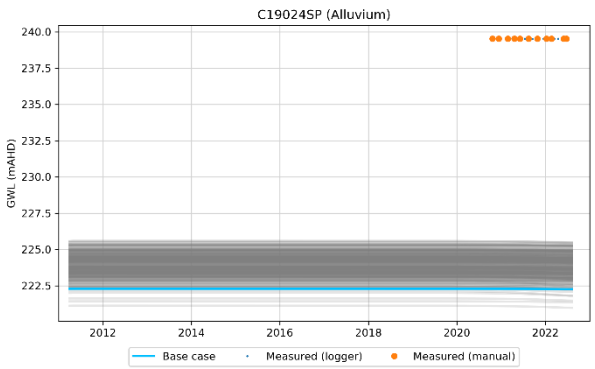
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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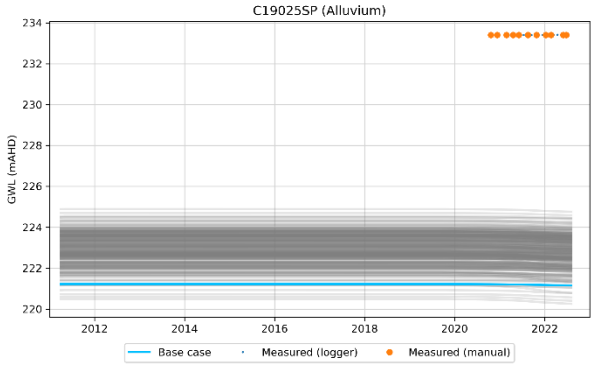
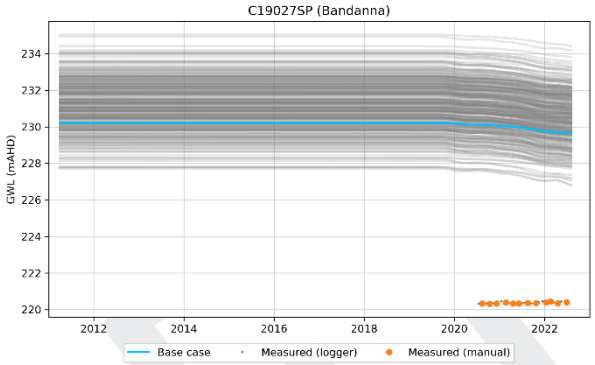
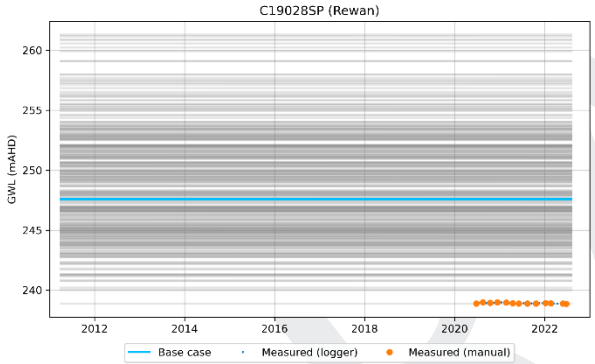
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


C19025SP (Alluvium)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


C19027SP (Bandanna)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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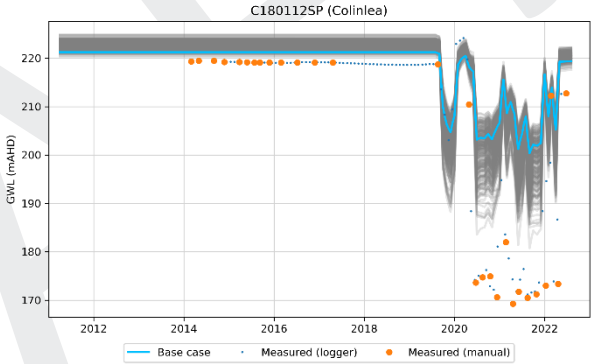
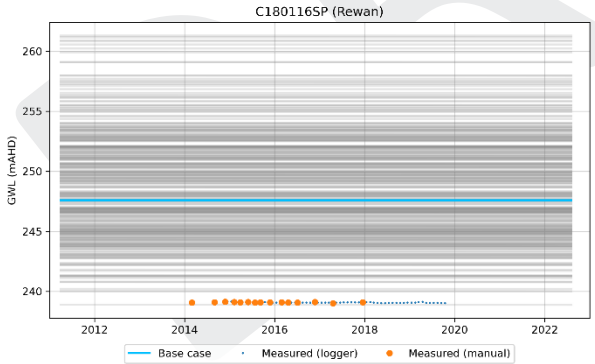
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


C180112SP (Colinlea)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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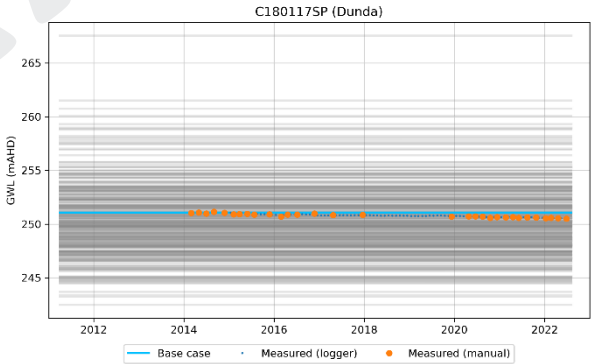
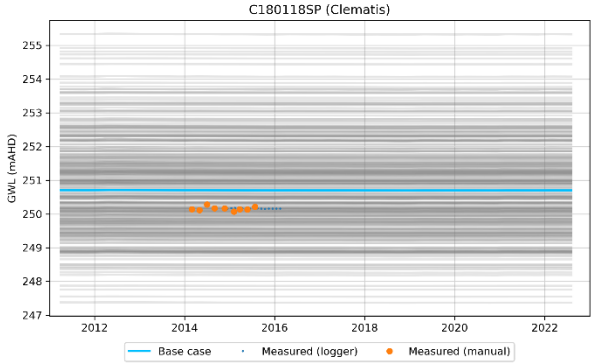
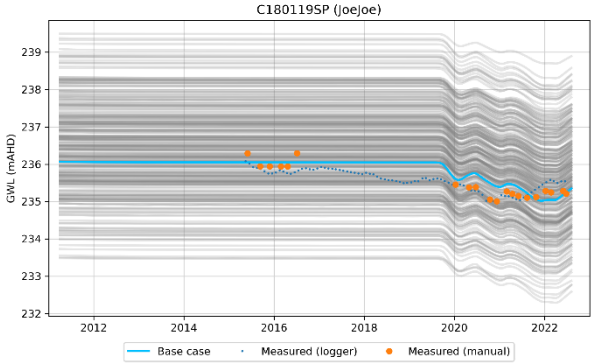
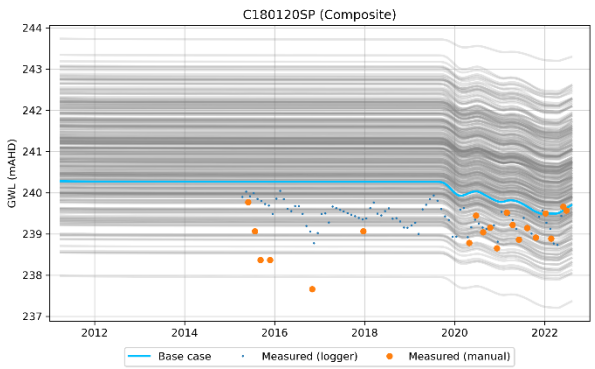
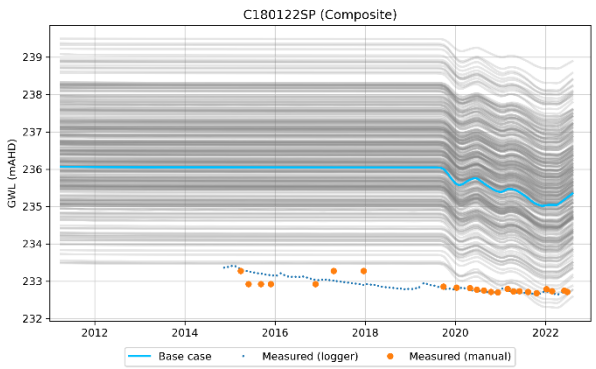
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

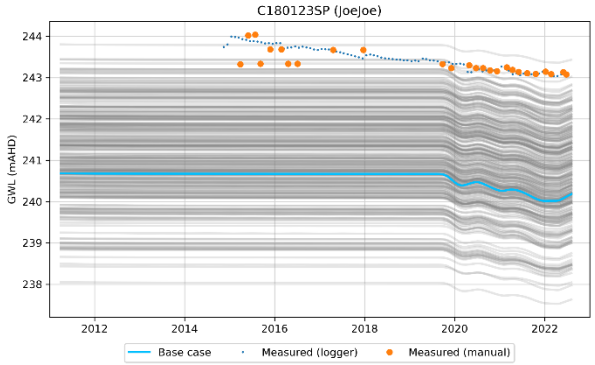

C180117SP (Dunda)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


C180118SP (Clematis)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


C180119SP (JoeJoe)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


C180120SP (Composite)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


C180122SP (Composite)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)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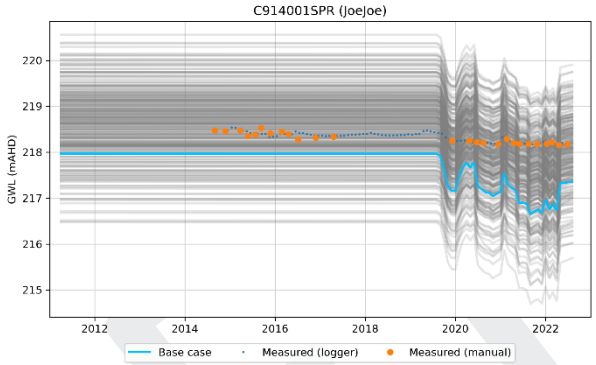
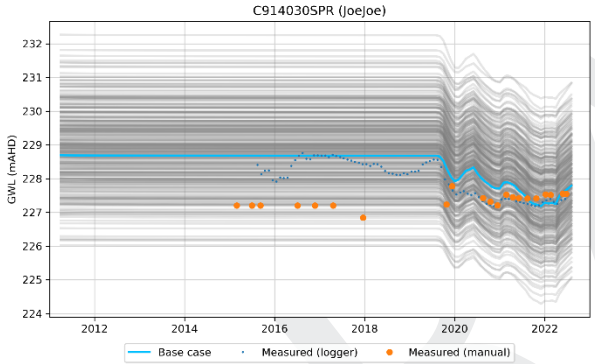
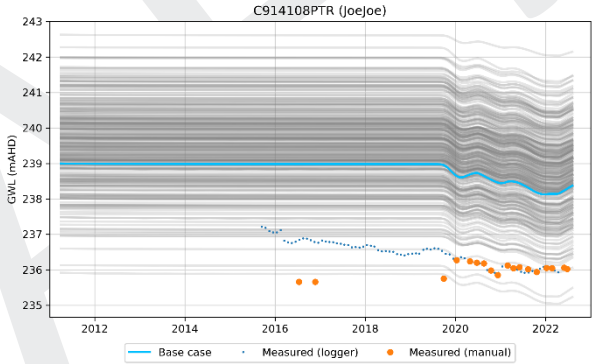
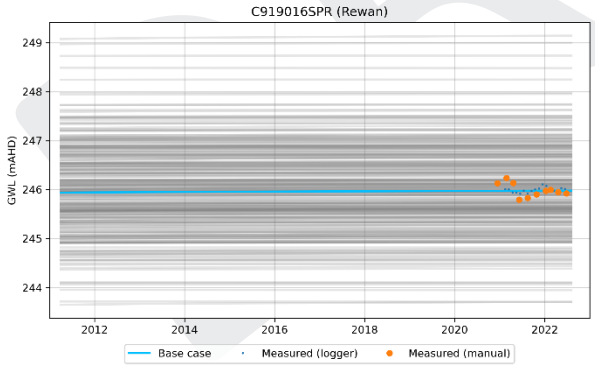
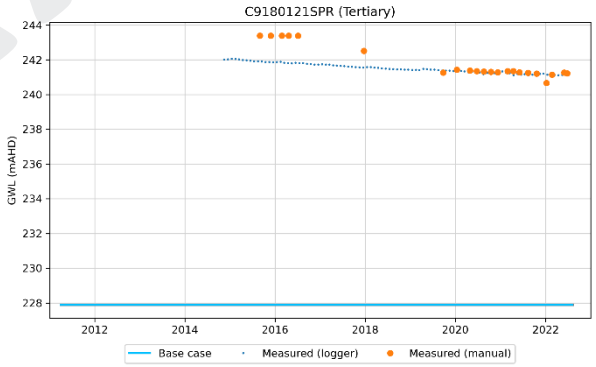
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

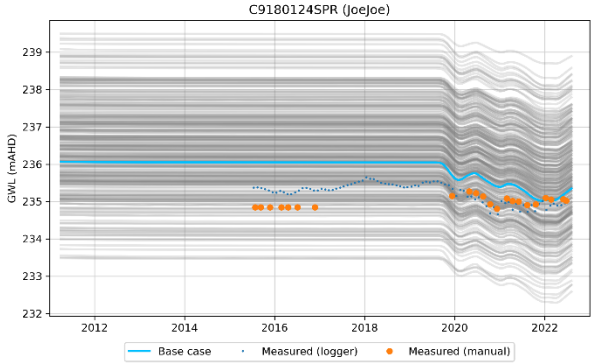

C914001SPR (JoeJoe)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

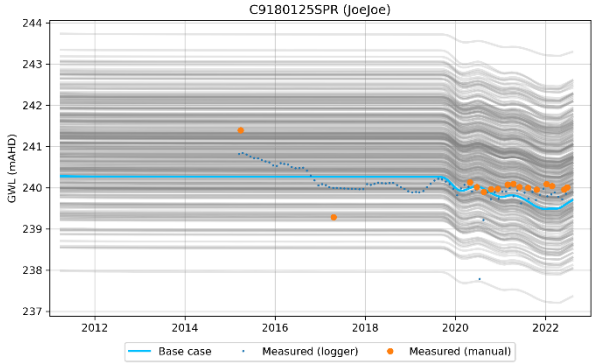

C914030SPR (JoeJoe)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

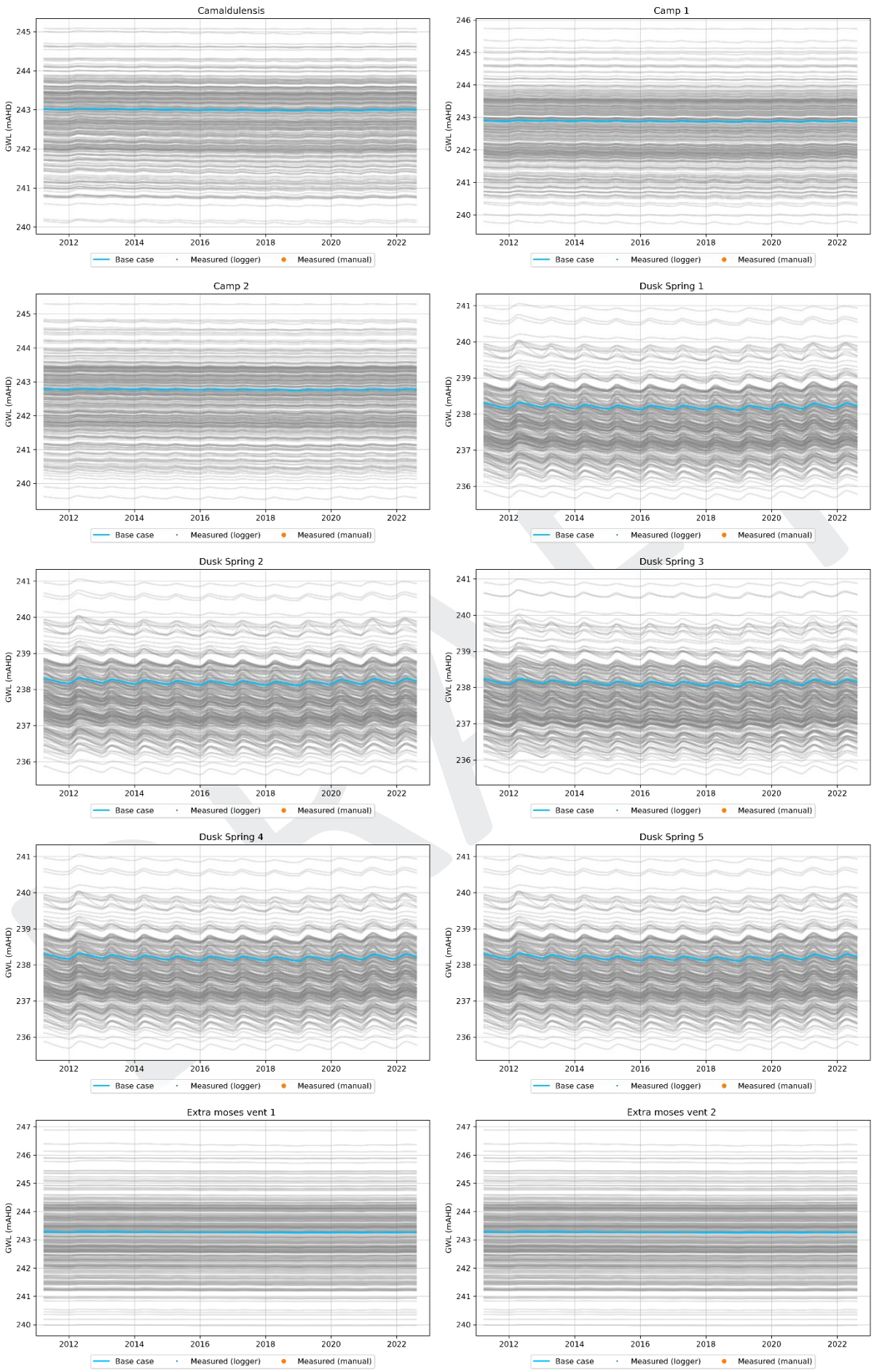

C914108PTR (JoeJoe)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

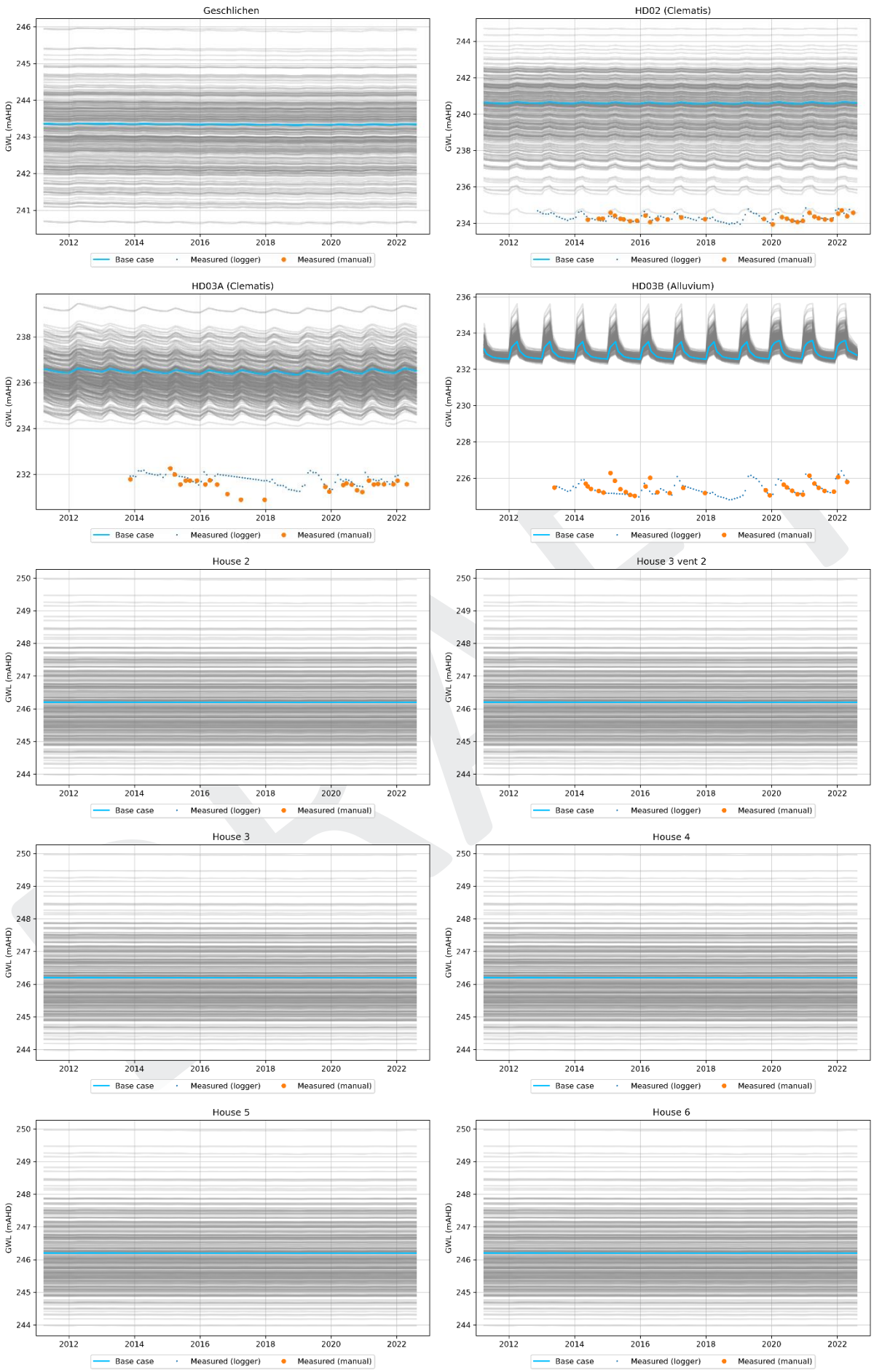

C919016SPR (Rewan)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

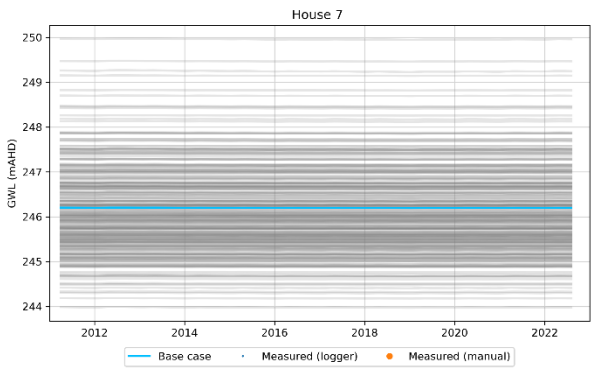

C9180121SPR (Tertiary)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

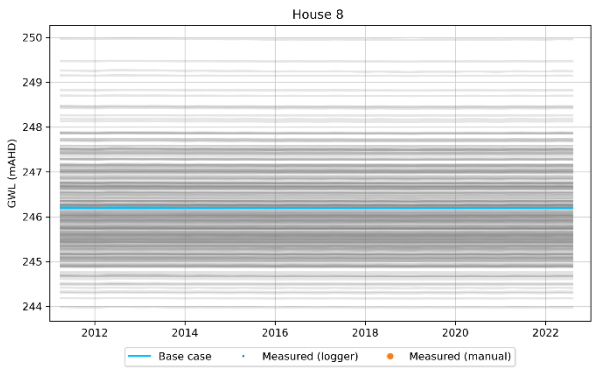

C9180124SPR (JoeJoe)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

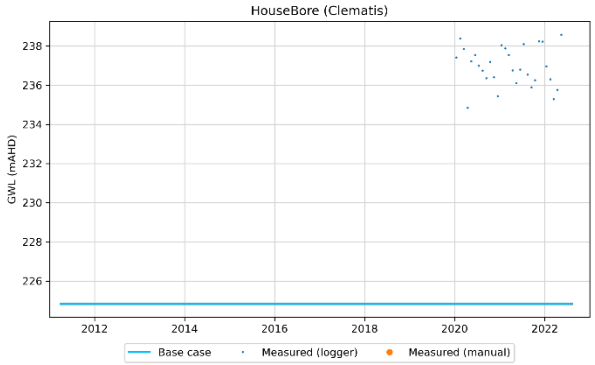

C9180125SPR (JoeJoe)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

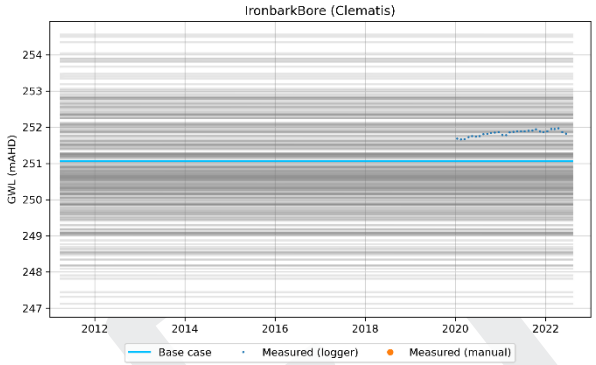

Camaldulensis
Camp 1
Camp 2
Dusk Spring 1
Dusk Spring 2
Dusk Spring 3
Dusk Spring 4
Dusk Spring 5
Extra moses vent 1
Extra moses vent 2
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

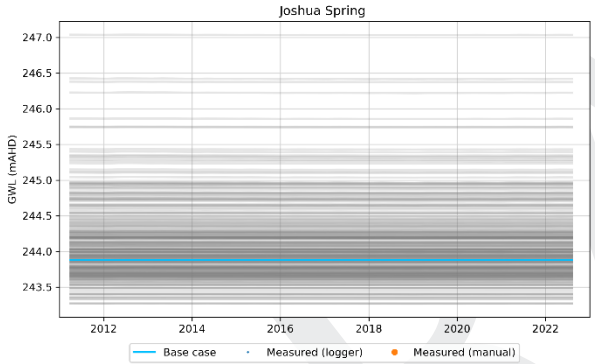

Geschlichen
HD02 (Clematis)
HD03A (Clematis)
HD03B (Alluvium)
House 2
House 3 vent 2
House 3
House 4
House 5
House 6
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

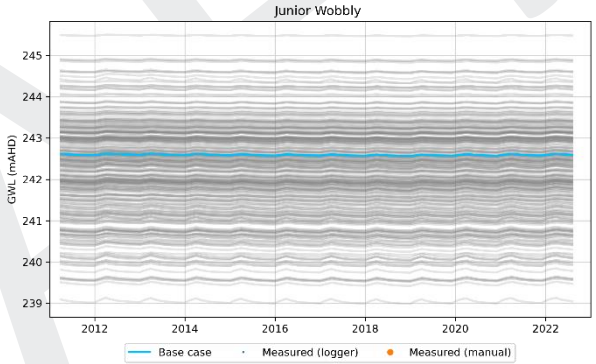

House 7
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

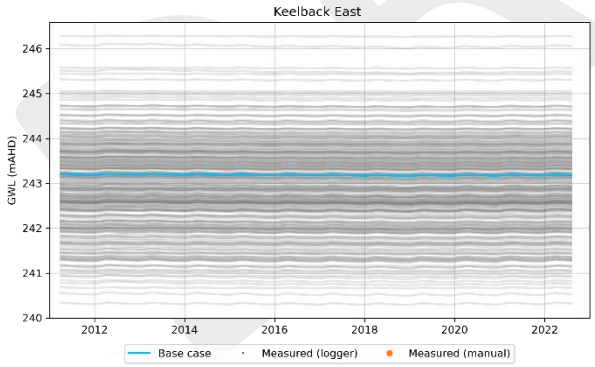

House 8
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

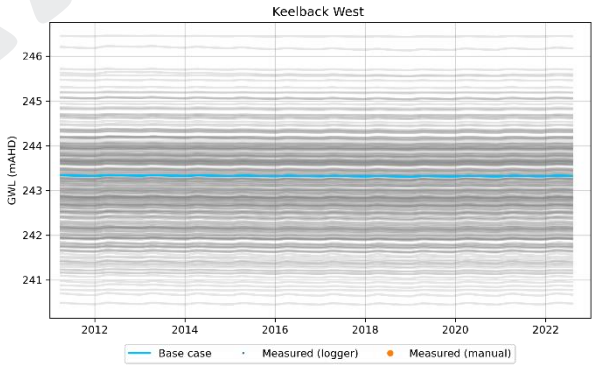

HouseBore (Clematis)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

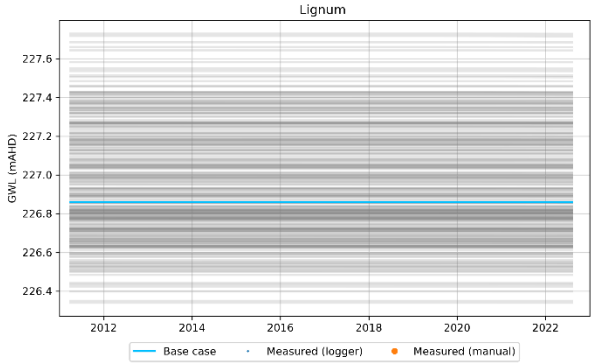

IronbarkBore (Clematis)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

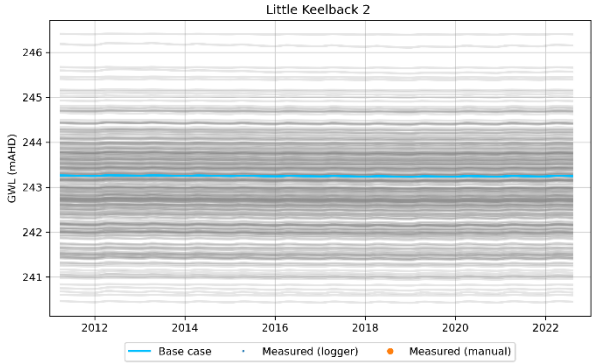

Joshua Spring
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

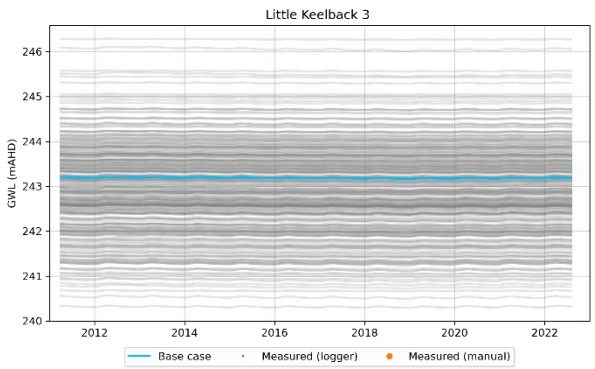

Junior Wobbly
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

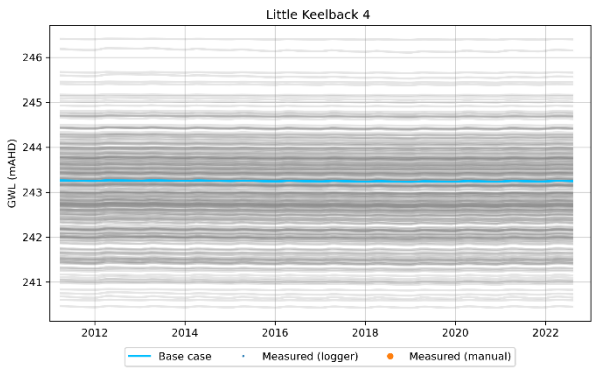

Keelback East
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

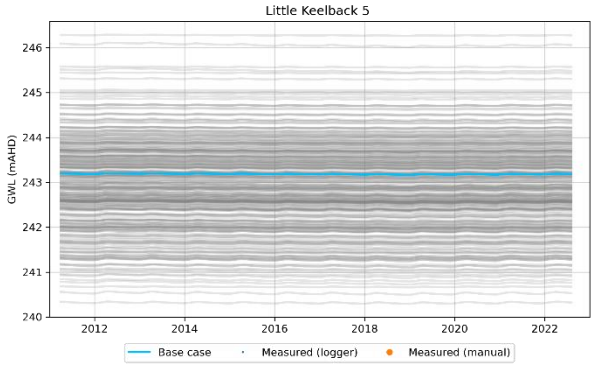

Keelback West
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

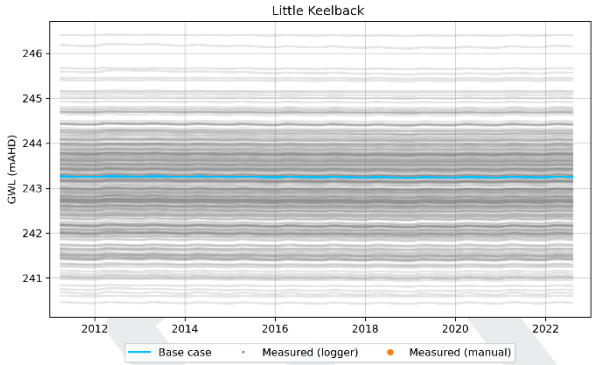

Lignum
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

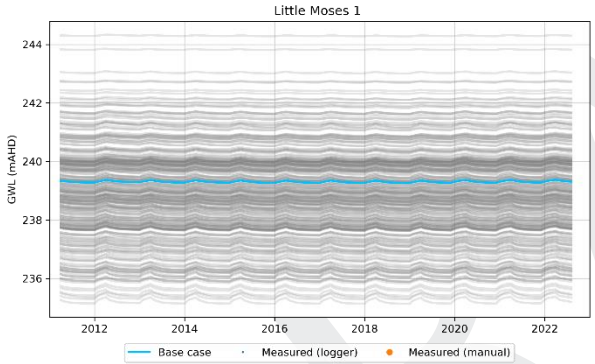

Little Keelback 2
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

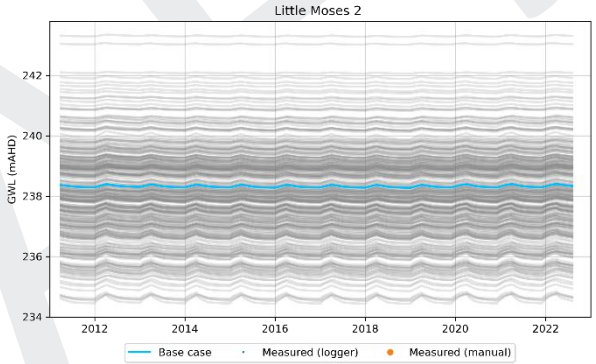

Little Keelback 3
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

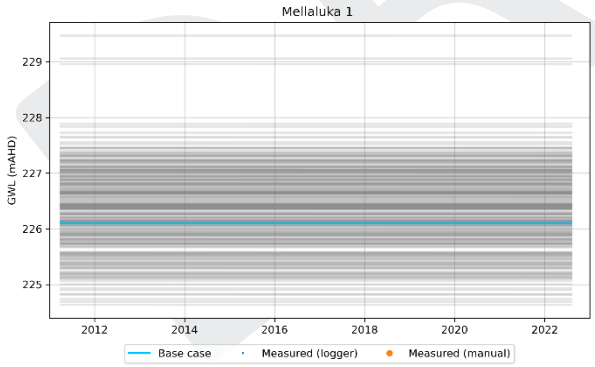

Little Keelback 4
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

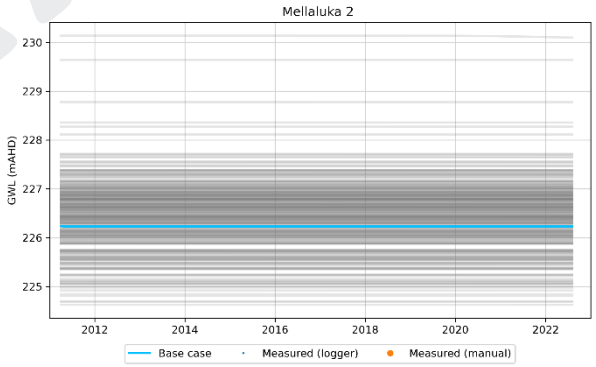

Little Keelback 5
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

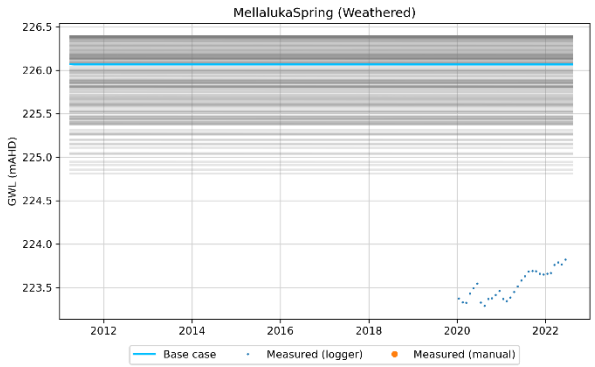

Little Keelback
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

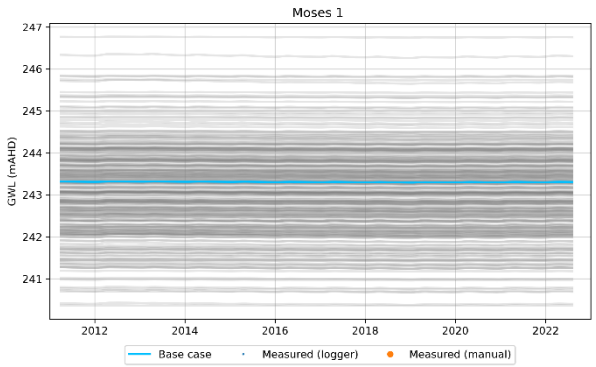

Little Moses 1
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

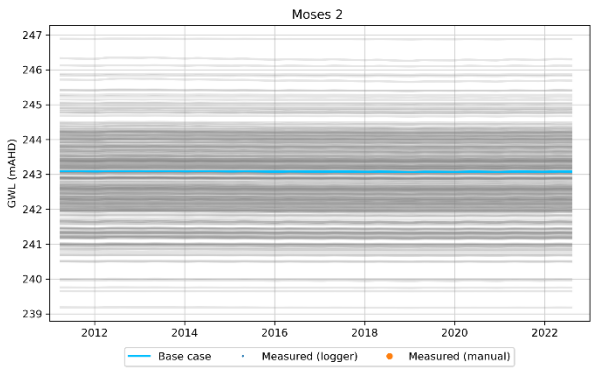

Little Moses 2
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


Mellaluka 1
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


Mellaluka 2
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


MellalukaSpring (Weathered)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


Moses 1
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


Moses 2
GWL (mAHD)
247
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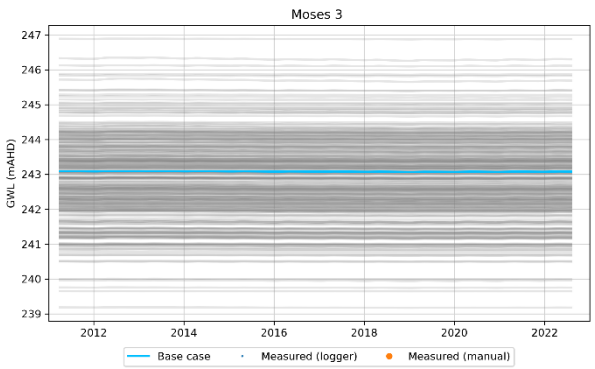
239
2012
2014
2016
2018
2020
2022
Base case
Measured (logger)
Measured (manual)


Moses 3
GWL (mAHD)
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2012
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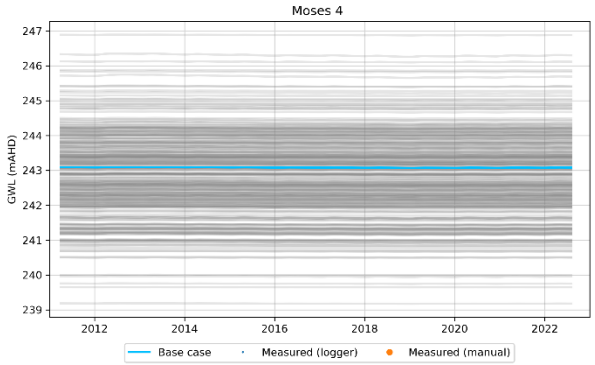
2020
2022
Base case
Measured (logger)
Measured (manual)


Moses 4
GWL (mAHD)
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2012
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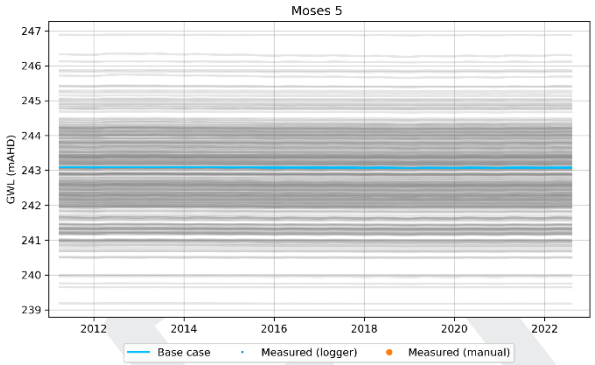
2022
Base case
Measured (logger)
Measured (manual)


Moses 5
GWL (mAHD)
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2012
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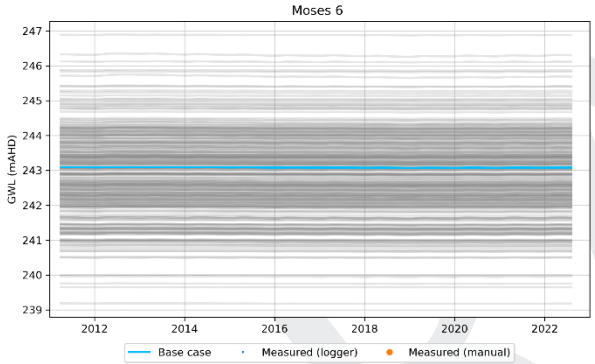
2022
Base case
Measured (logger)
Measured (manual)


Moses 6
GWL (mAHD)
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2012
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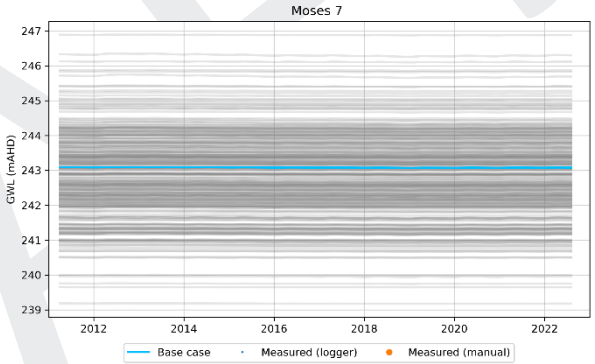
2020
2022
Base case
Measured (logger)
Measured (manual)


Moses 7
GWL (mAHD)
247
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2012
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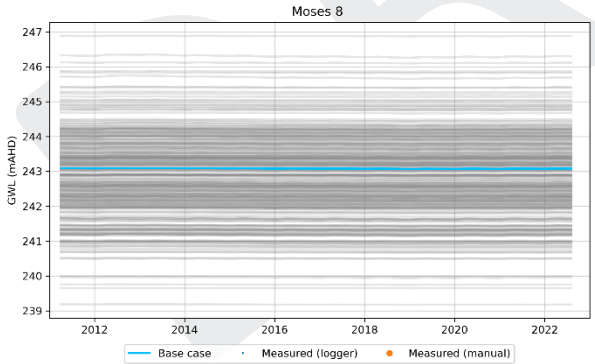
2022
Base case
Measured (logger)
Measured (manual)


Moses 8
GWL (mAHD)
247
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2012
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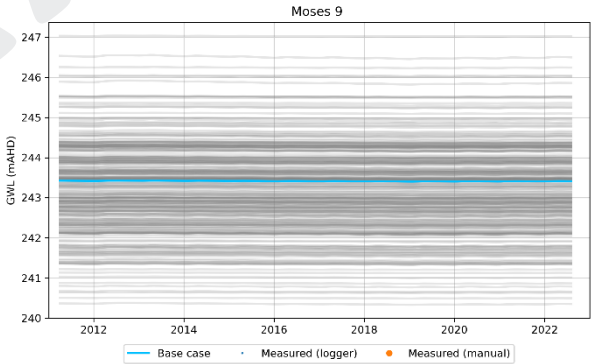
2022
Base case
Measured (logger)
Measured (manual)


Moses 9
GWL (mAHD)
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2012
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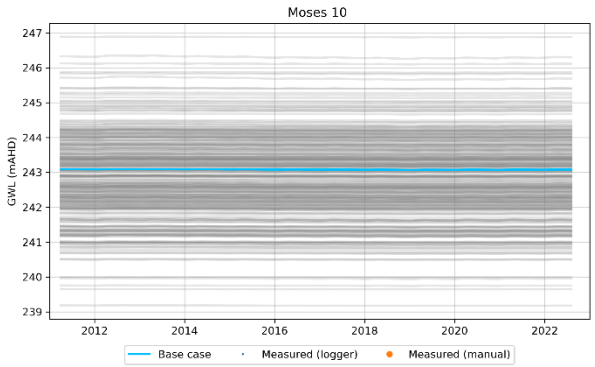
2022
Base case
Measured (logger)
Measured (manual)


Moses 10
GWL (mAHD)
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2012
2014
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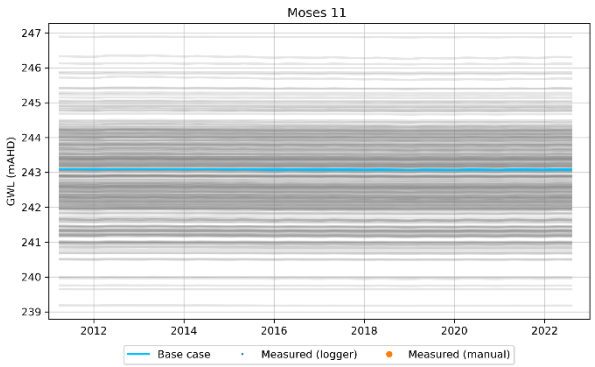
2022
Base case
Measured (logger)
Measured (manual)


Moses 11
GWL (mAHD)
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2012
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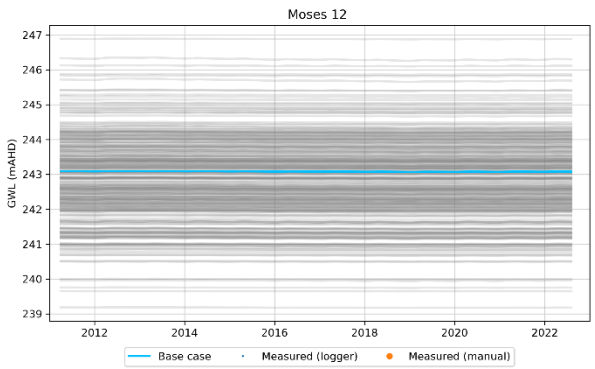
2022
Base case
Measured (logger)
Measured (manual)


Moses 12
GWL (mAHD)
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2012
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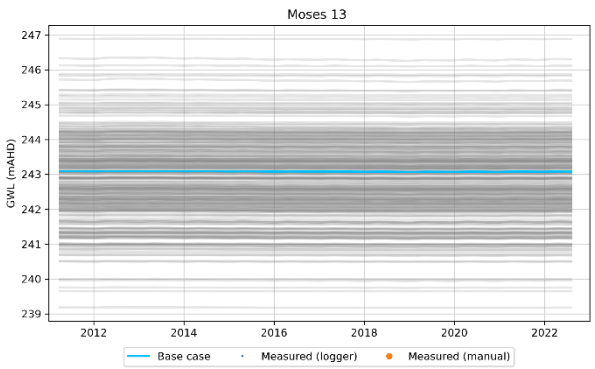
2022
Base case
Measured (logger)
Measured (manual)


Moses 13
GWL (mAHD)
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240
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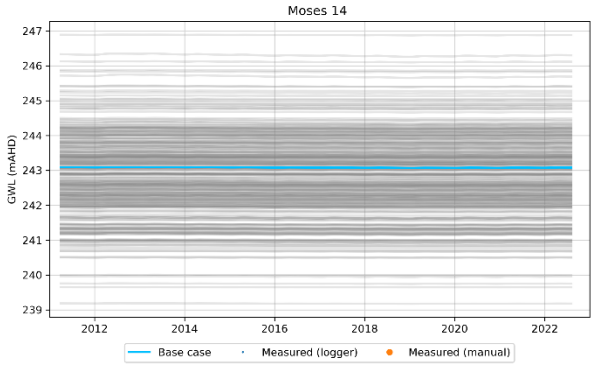
2012
2014
2016
2018
2020
2022
Base case
Measured (logger)
Measured (manual)


Moses 14
GWL (mAHD)
247
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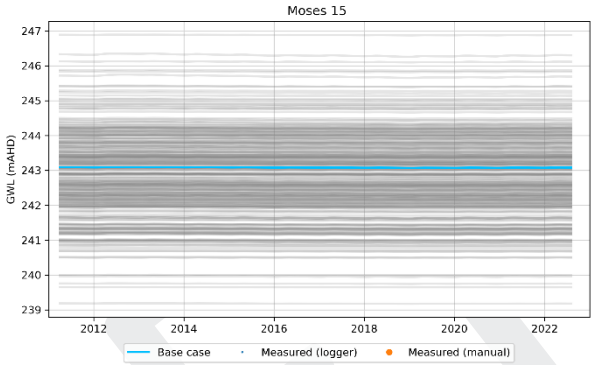
2012
2014
2016
2018
2020
2022
Base case
Measured (logger)
Measured (manual)


Moses 15
GWL (mAHD)
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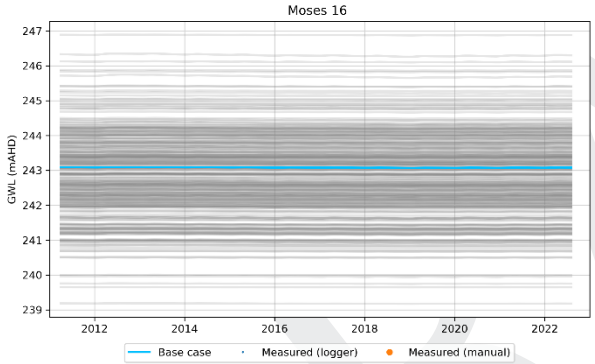
2012
2014
2016
2018
2020
2022
Base case
Measured (logger)
Measured (manual)


Moses 16
GWL (mAHD)
247
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2012
2014
2016
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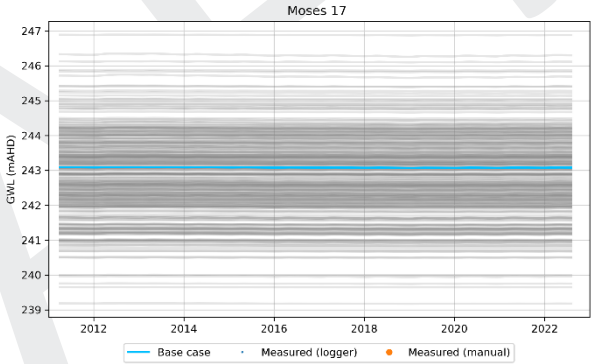
2020
2022
Base case
Measured (logger)
Measured (manual)


Moses 17
GWL (mAHD)
247
246
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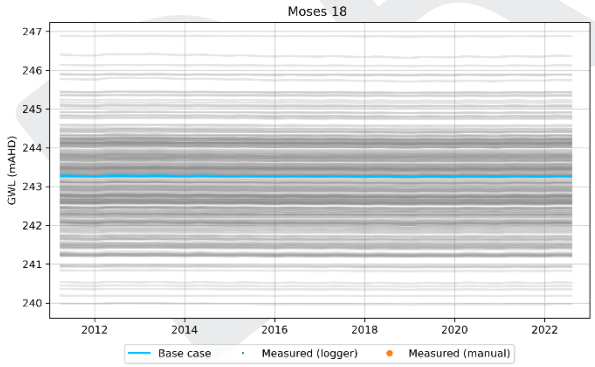
239
2012
2014
2016
2018
2020
2022
Base case
Measured (logger)
Measured (manual)


Moses 18
GWL (mAHD)
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2012
2014
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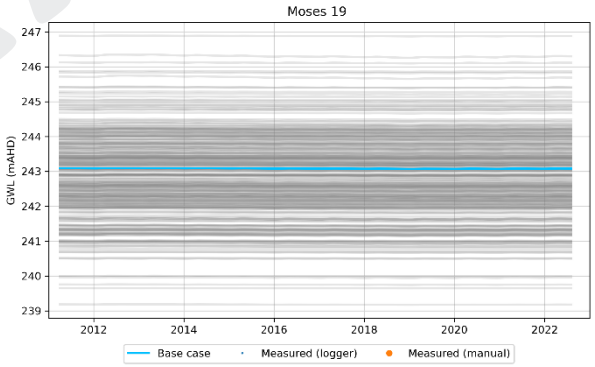
2018
2020
2022
Base case
Measured (logger)
Measured (manual)


Moses 19
GWL (mAHD)
247
246
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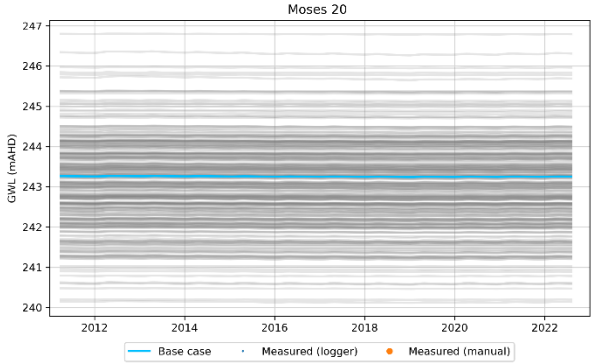
242
241
240
239
2012
2014
2016
2018
2020
2022
Base case
Measured (logger)
Measured (manual)


Moses 20
GWL (mAHD)
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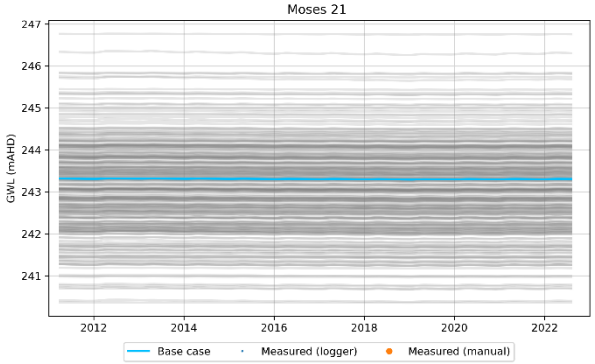
240
2012
2014
2016
2018
2020
2022
Base case
Measured (logger)
Measured (manual)


Moses 21
GWL (mAHD)
247
246
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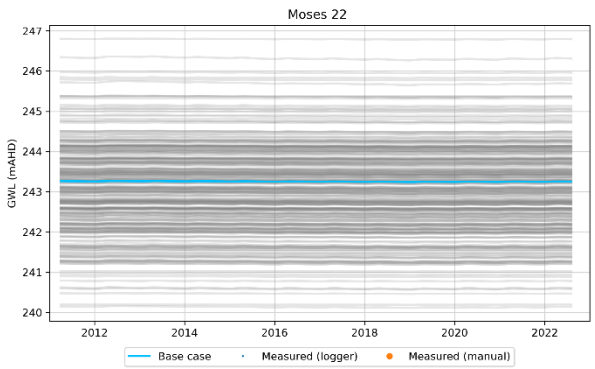
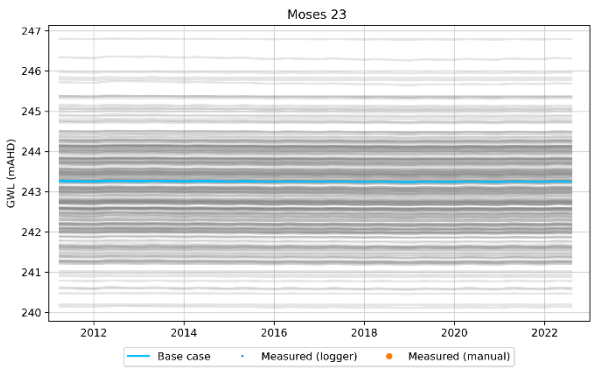
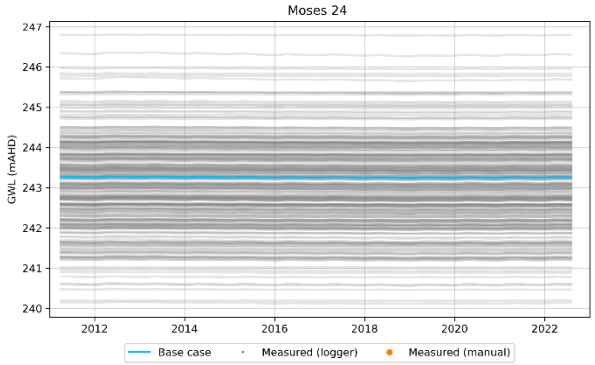
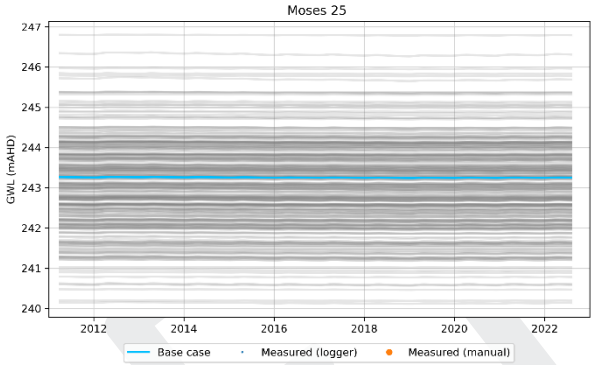
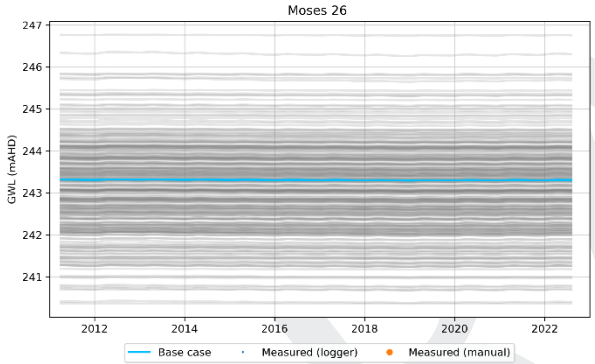
243
242
241
2012
2014
2016
2018
2020
2022
Base case
Measured (logger)
Measured (manual)

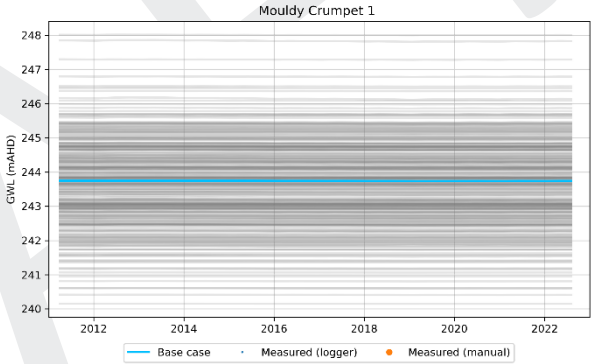

Moses 22
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

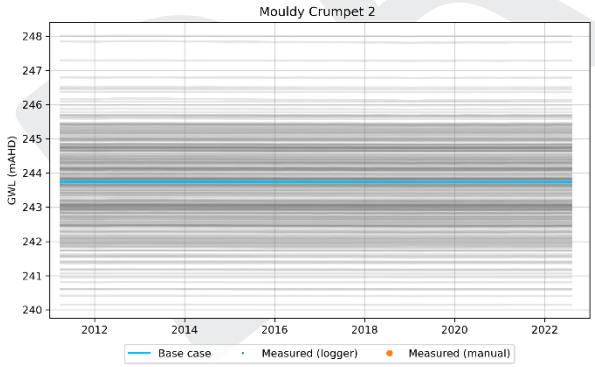

Moses 23
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

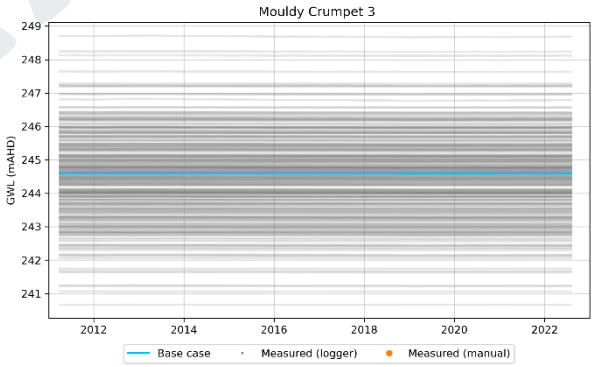

Moses 24
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

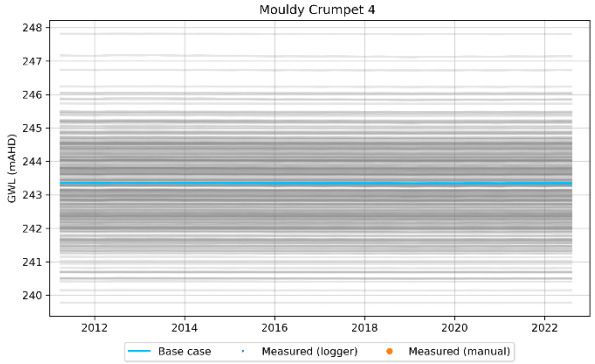

Moses 25
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

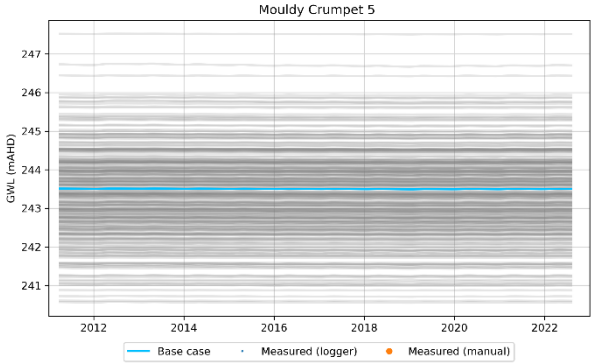

Moses 26
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

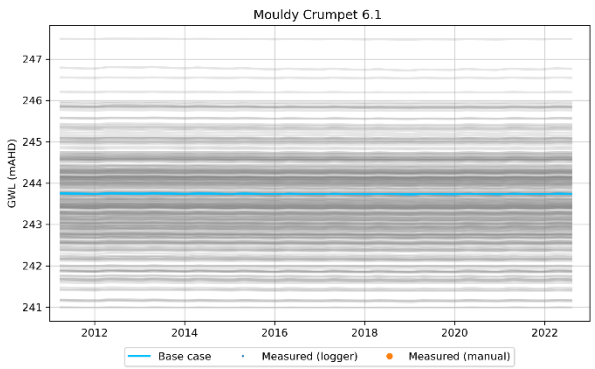

Mouldy Crumpet 1
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

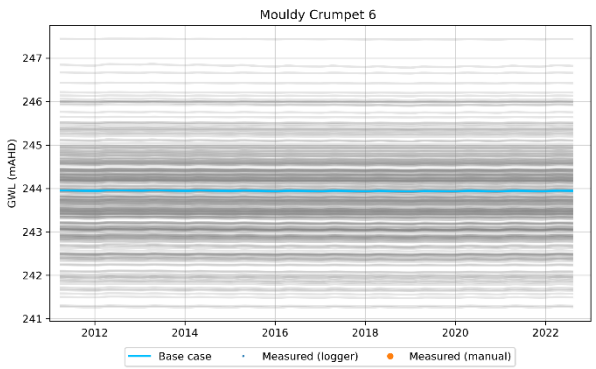

Mouldy Crumpet 2
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

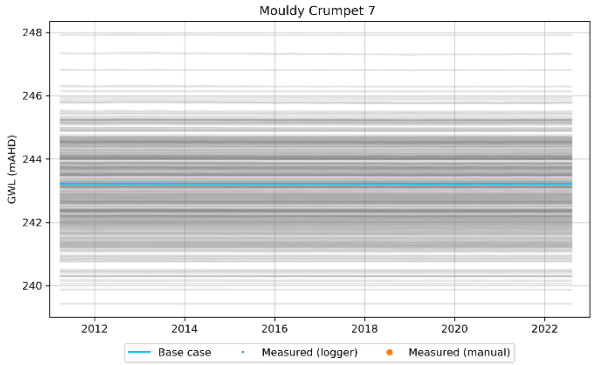

Mouldy Crumpet 3
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

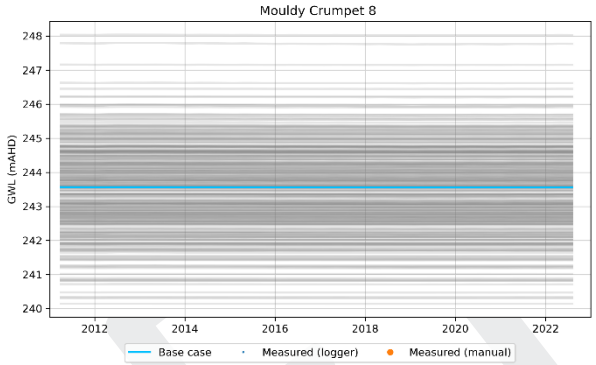

Mouldy Crumpet 4
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

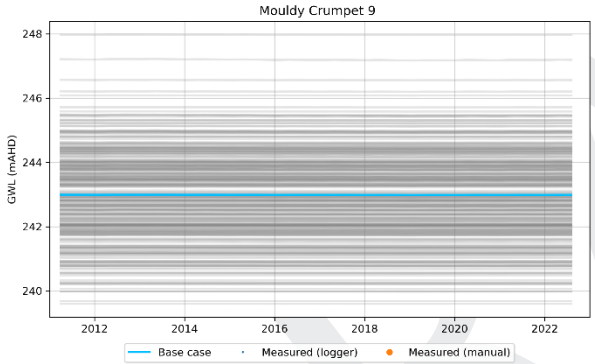

Mouldy Crumpet 5
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

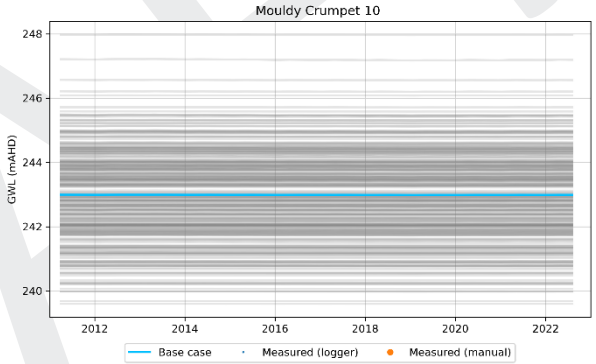

Mouldy Crumpet 6.1
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

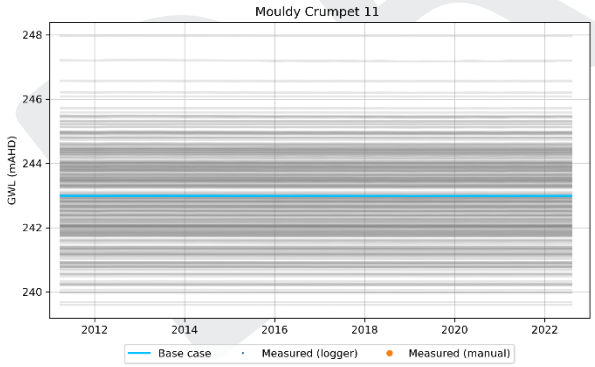

Mouldy Crumpet 6
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

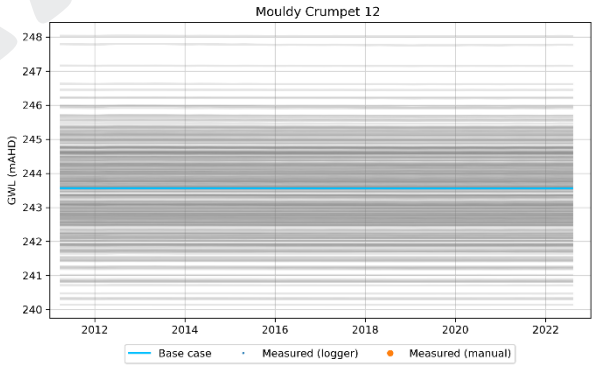

Mouldy Crumpet 7
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

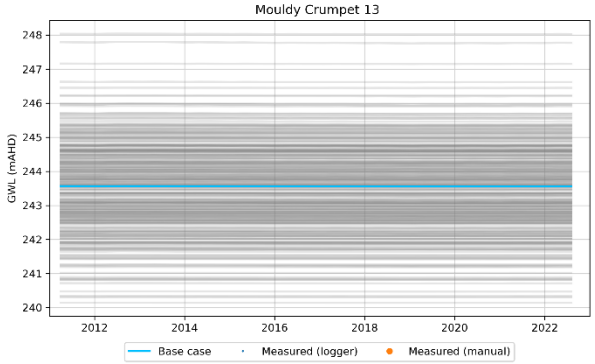

Mouldy Crumpet 8
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

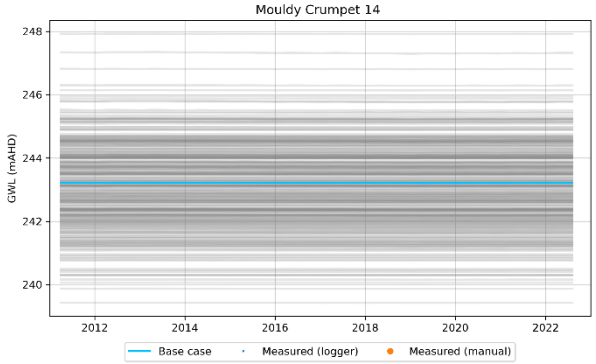

Mouldy Crumpet 9
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

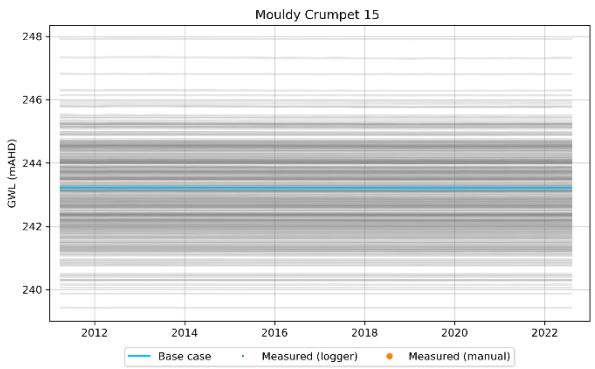

Mouldy Crumpet 10
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

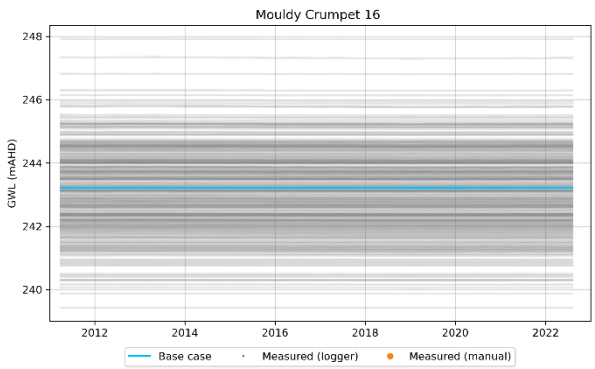

Mouldy Crumpet 11
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 12
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 13
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 14
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 15
GWL (mAHD)
248
246
244
242
240
2012
2014
2016
2018
2020
2022
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 16
GWL (mAHD)
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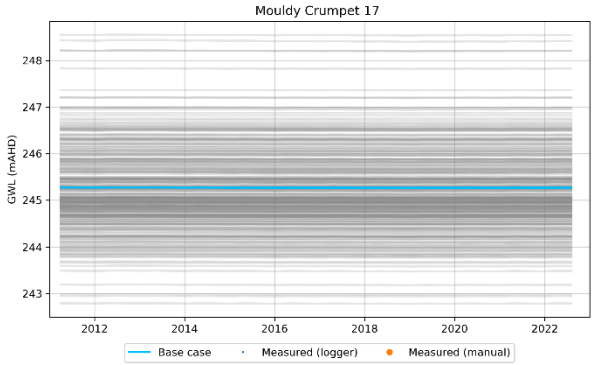
246
244
242
240
2012
2014
2016
2018
2020
2022
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 17
GWL (mAHD)
248
247
246
245
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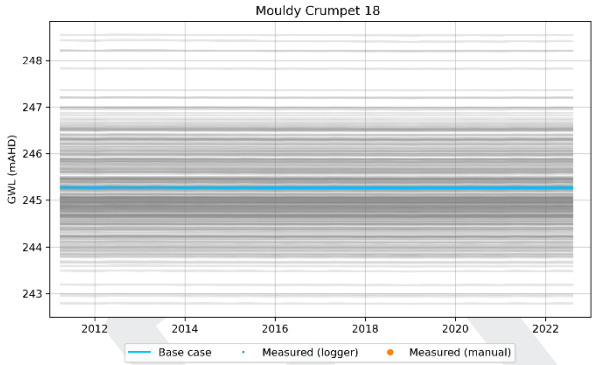
243
2012
2014
2016
2018
2020
2022
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 18
GWL (mAHD)
248
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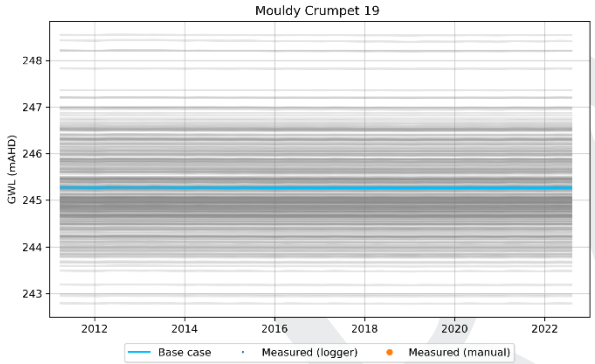
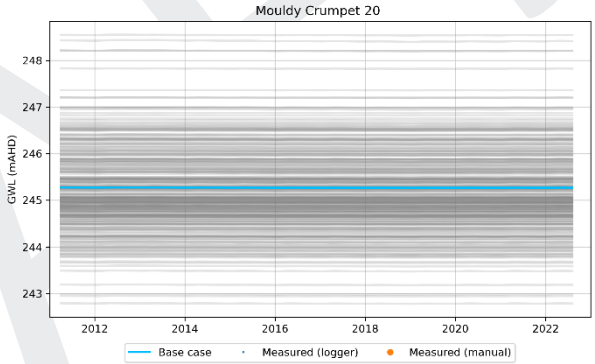
246
245
244
243
2012
2014
2016
2018
2020
2022
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 19
GWL (mAHD)
248
247
246
245
244
243
2012
2014
2016
2018
2020
2022
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 20
GWL (mAHD)
248
247
246
245
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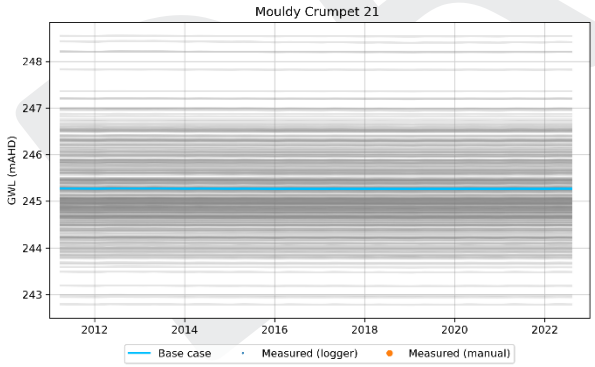
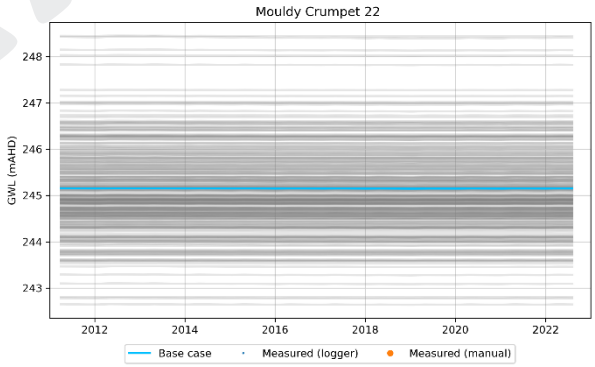
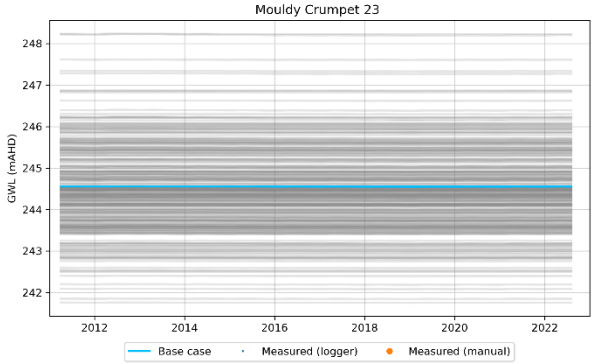
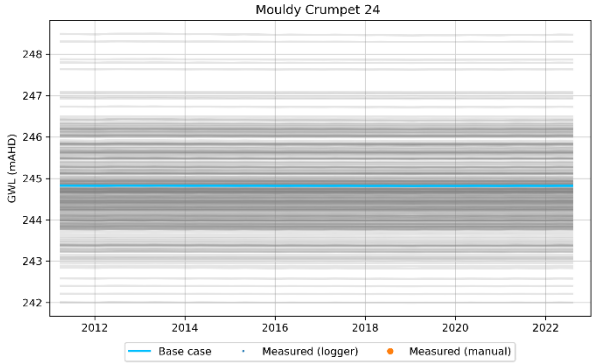
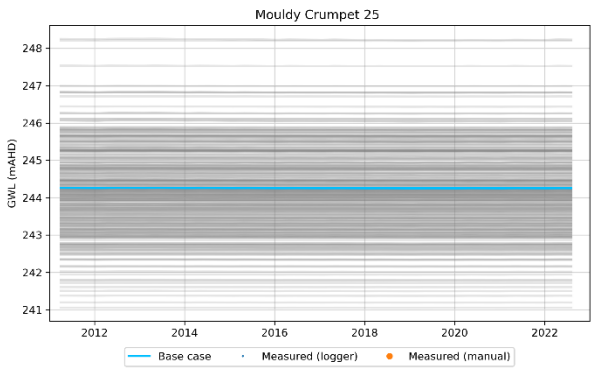
243
2012
2014
2016
2018
2020
2022
Base case
Measured (logger)
Measured (manual)

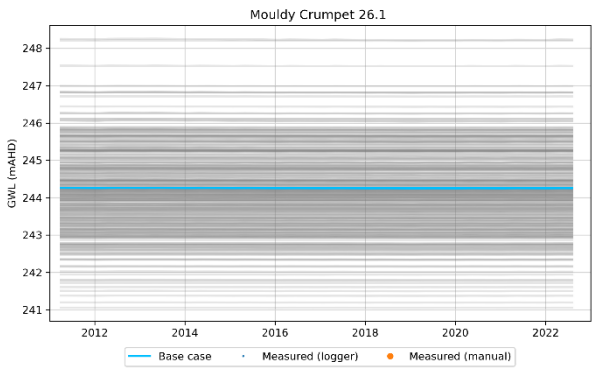

Mouldy Crumpet 21
GWL (mAHD)
248
247
246
245
244
243
2012
2014
2016
2018
2020
2022
Base case
Measured (logger)
Measured (manual)

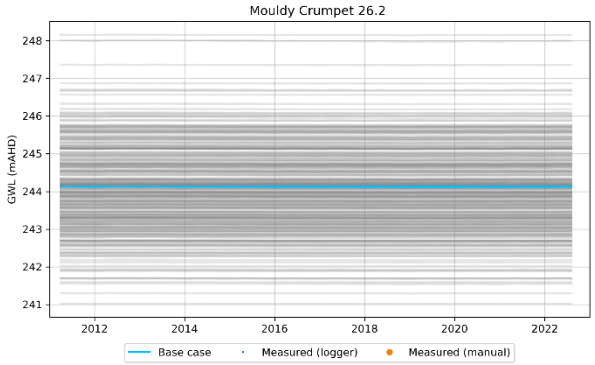

Mouldy Crumpet 22
GWL (mAHD)
248
247
246
245
244
243
2012
2014
2016
2018
2020
2022
Base case
Measured (logger)
Measured (manual)

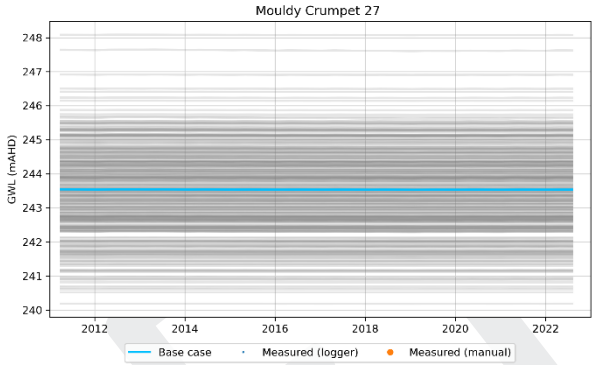

Mouldy Crumpet 23
GWL (mAHD)
248
247
246
245
244
243
242
2012
2014
2016
2018
2020
2022
Base case
Measured (logger)
Measured (manual)

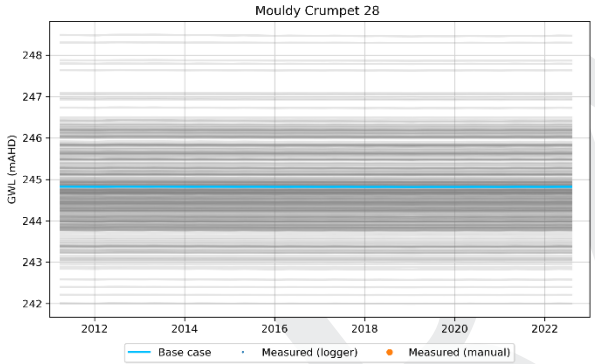

Mouldy Crumpet 24
GWL (mAHD)
248
247
246
245
244
243
242
2012
2014
2016
2018
2020
2022
Base case
Measured (logger)
Measured (manual)

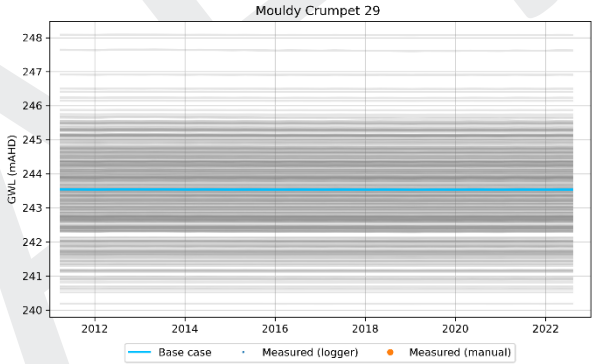

Mouldy Crumpet 25
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

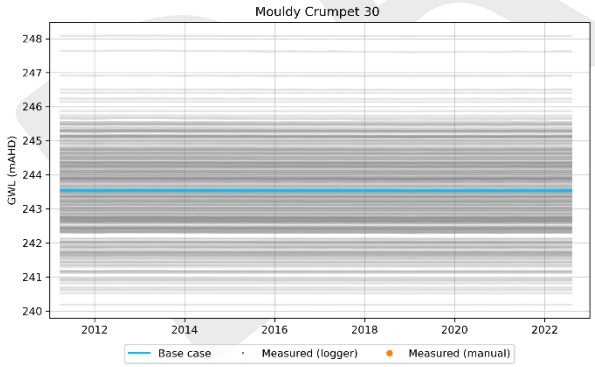

Mouldy Crumpet 26.1
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

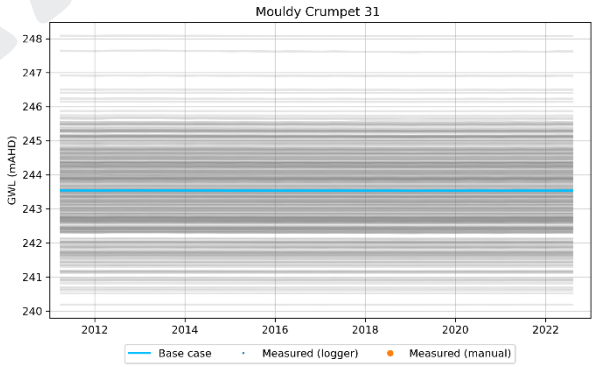

Mouldy Crumpet 26.2
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

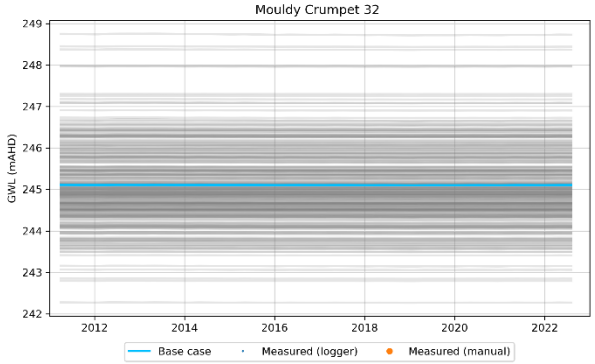

Mouldy Crumpet 27
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

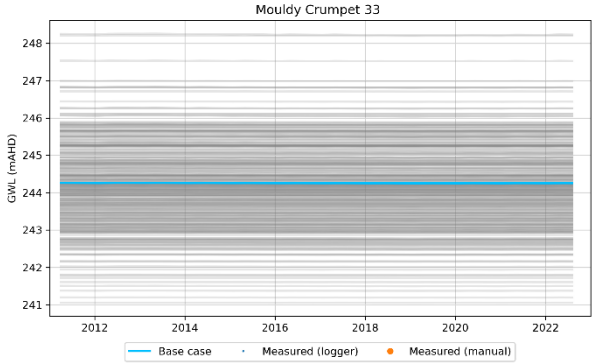

Mouldy Crumpet 28
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

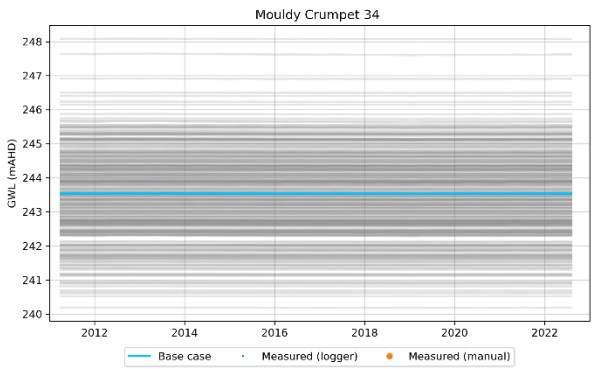

Mouldy Crumpet 29
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

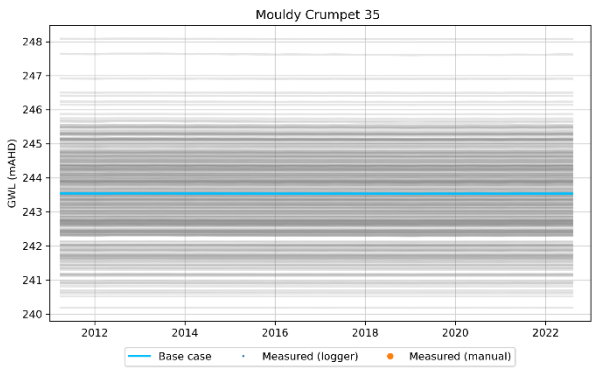

Mouldy Crumpet 30
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

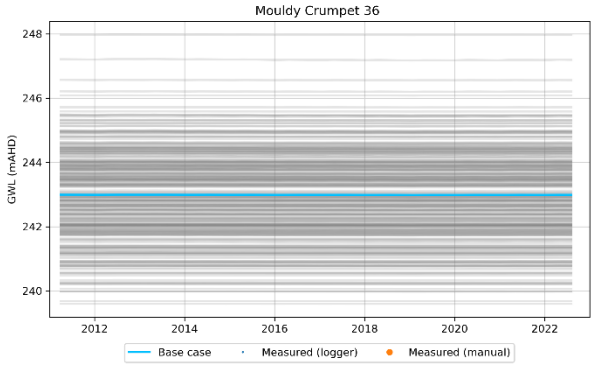

Mouldy Crumpet 31
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

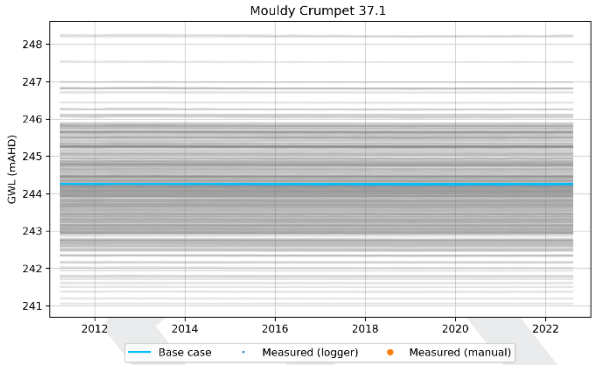

Mouldy Crumpet 32
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

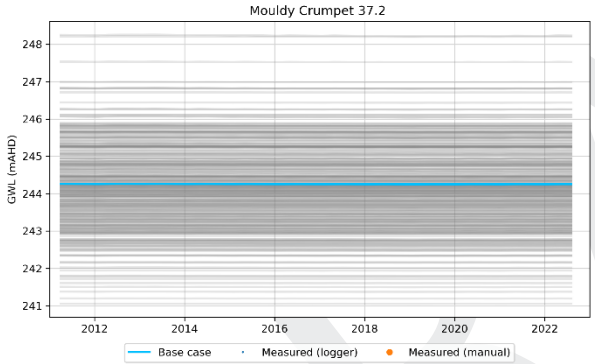

Mouldy Crumpet 33
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

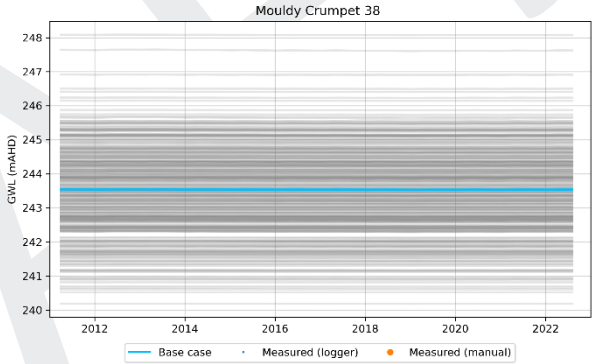

Mouldy Crumpet 34
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

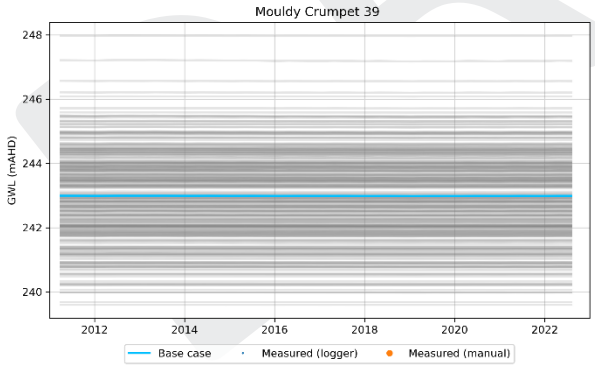

Mouldy Crumpet 35
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

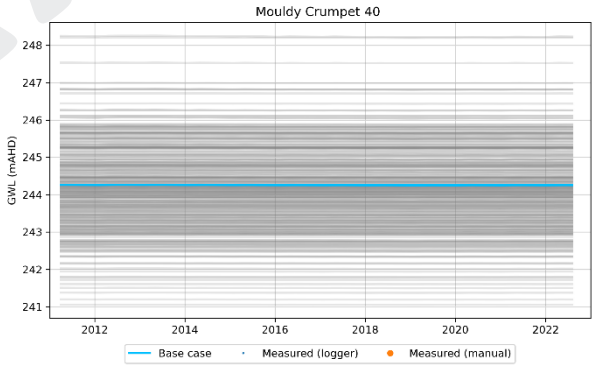

Mouldy Crumpet 36
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

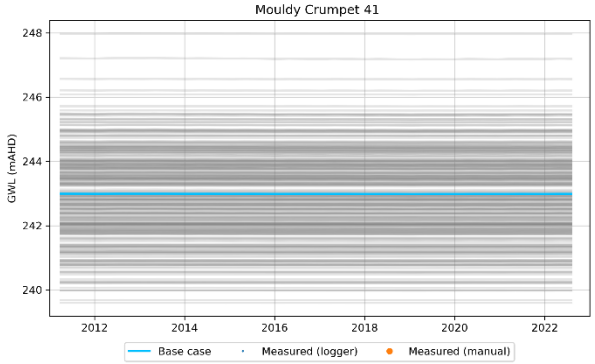

Mouldy Crumpet 37.1
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

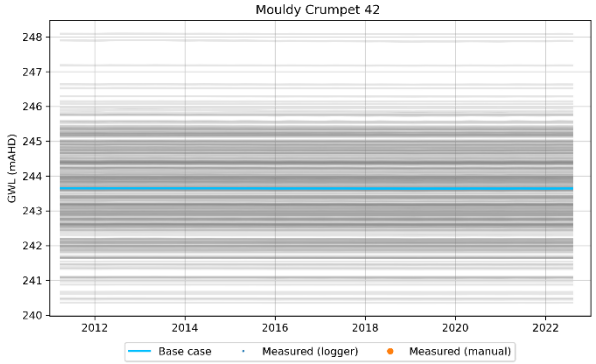

Mouldy Crumpet 37.2
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

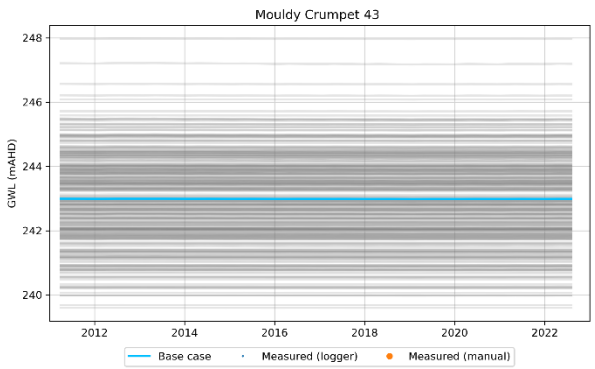

Mouldy Crumpet 38
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 39
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 40
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 41
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 42
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 43
GWL (mAHD)
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2012
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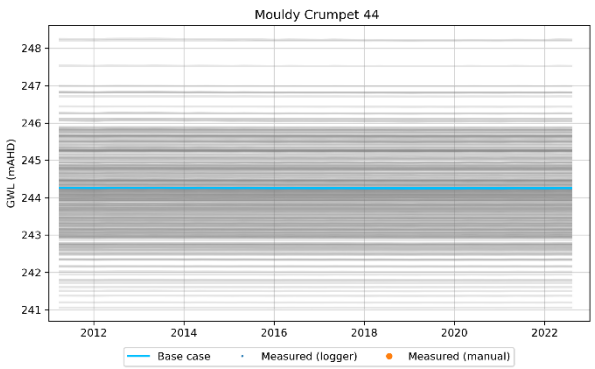
2022
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 44
GWL (mAHD)
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2012
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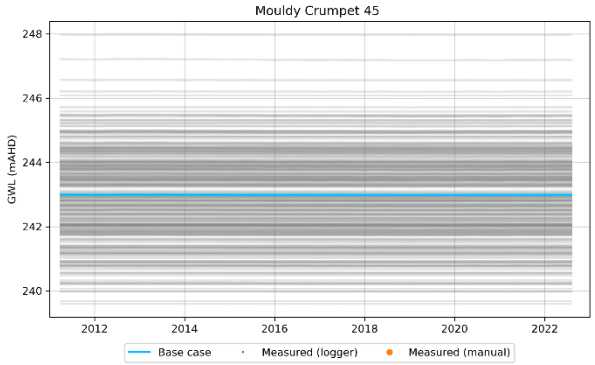
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 45
GWL (mAHD)
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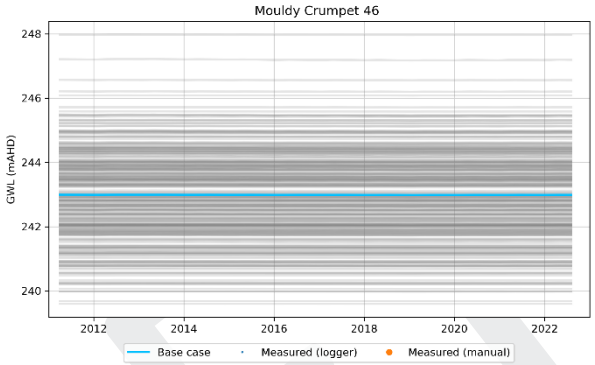
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 46
GWL (mAHD)
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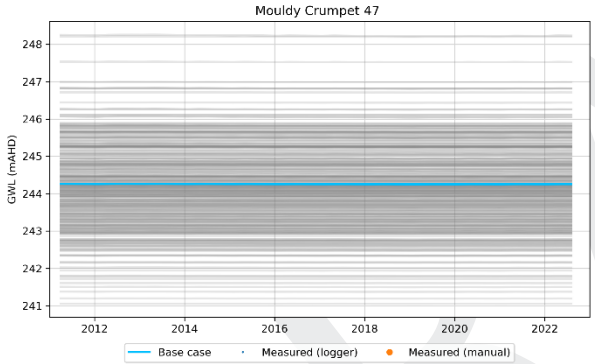
2022
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 47
GWL (mAHD)
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2012
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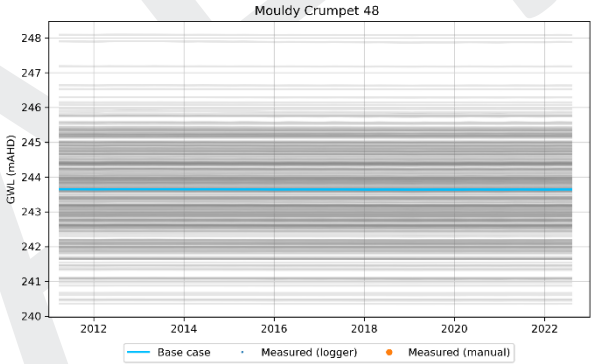
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 48
GWL (mAHD)
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2012
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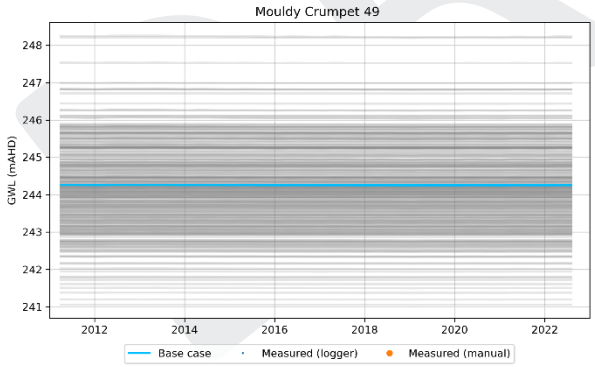
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 49
GWL (mAHD)
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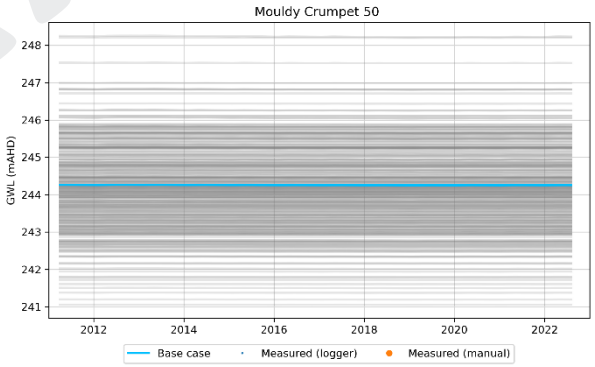
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 50
GWL (mAHD)
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2012
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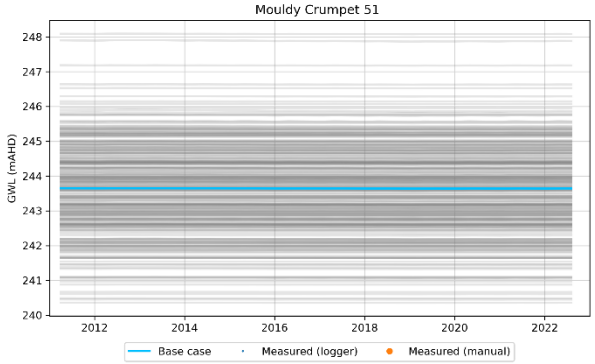
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 51
GWL (mAHD)
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2012
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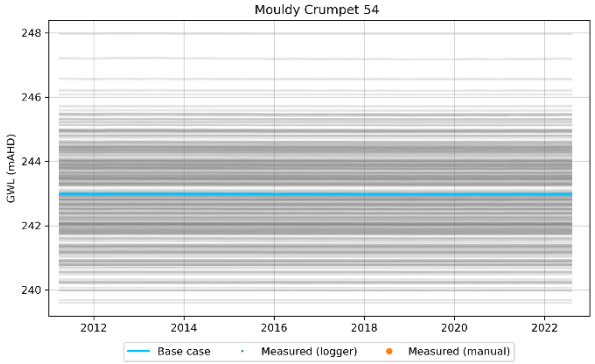
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 54
GWL (mAHD)
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2012
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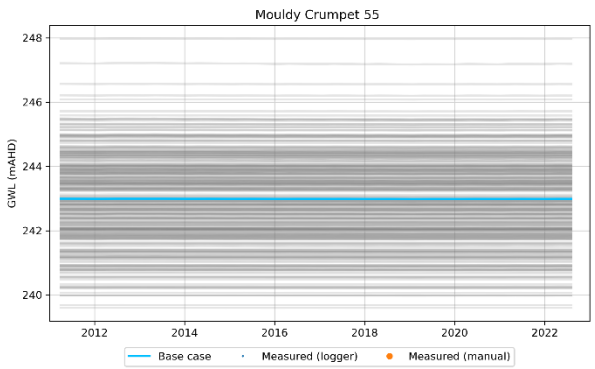
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 55
GWL (mAHD)
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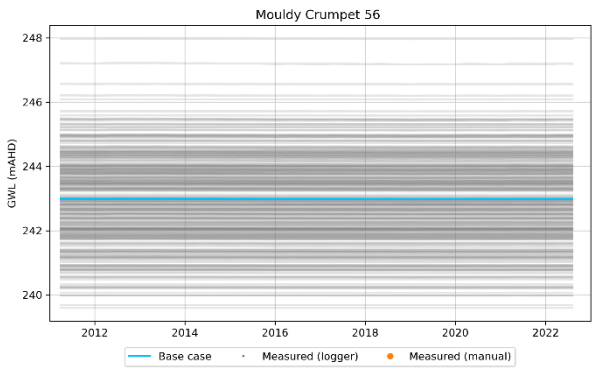
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 56
GWL (mAHD)
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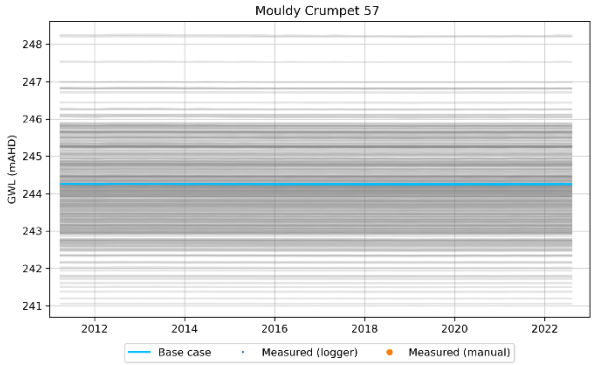
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 57
GWL (mAHD)
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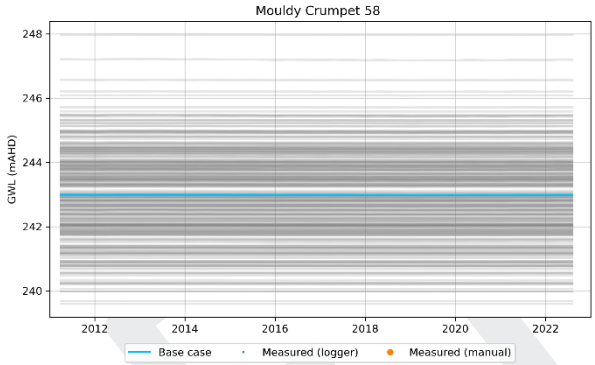
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 58
GWL (mAHD)
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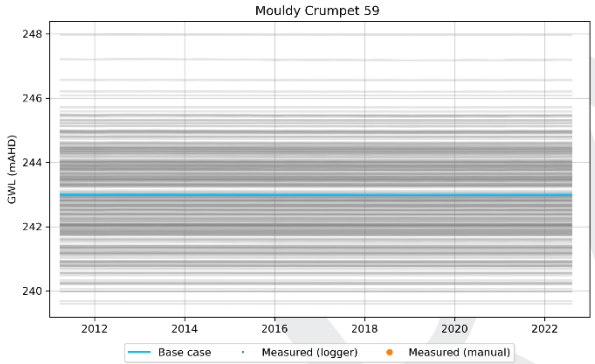
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 59
GWL (mAHD)
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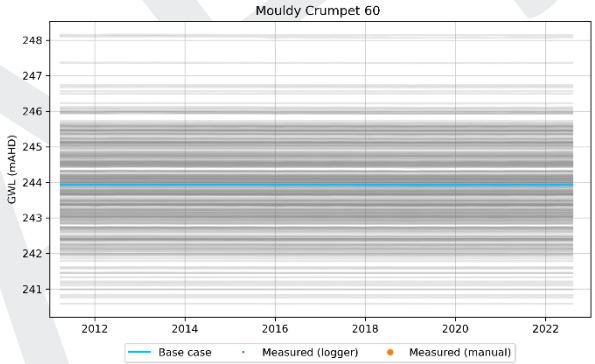
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 60
GWL (mAHD)
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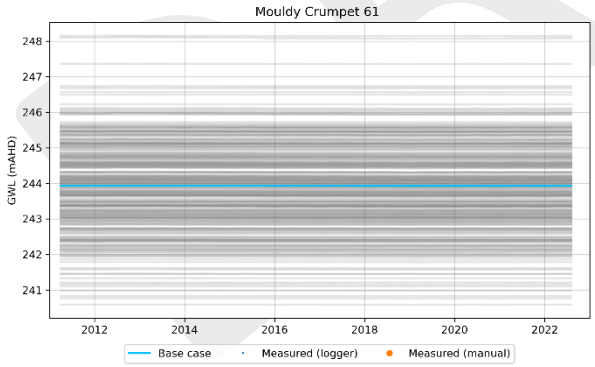
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 61
GWL (mAHD)
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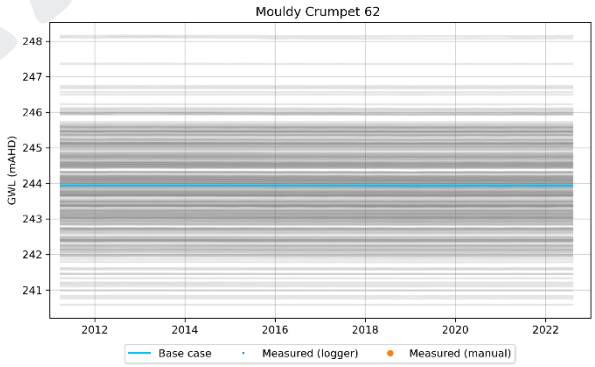
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 62
GWL (mAHD)
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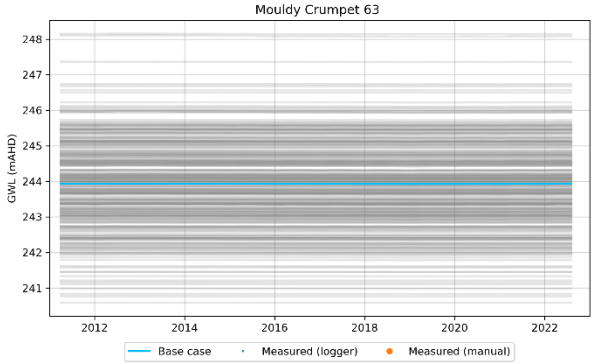
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 63
GWL (mAHD)
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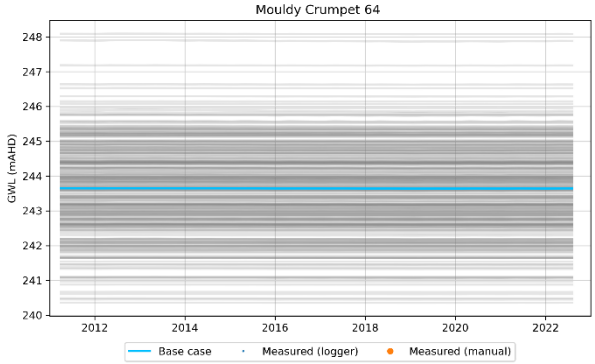
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 64
GWL (mAHD)
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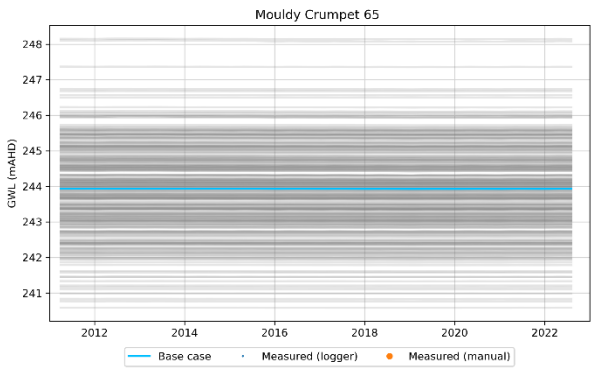
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 65
GWL (mAHD)
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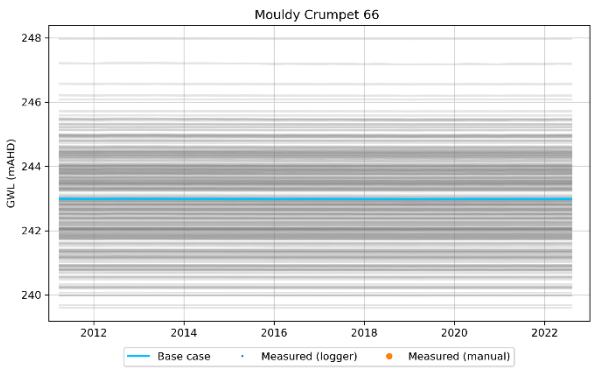
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 66
GWL (mAHD)
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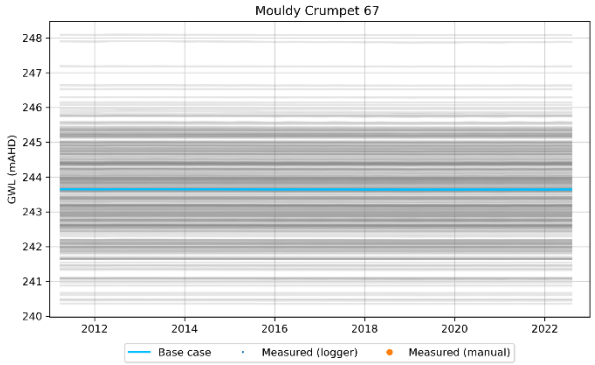
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 67
GWL (mAHD)
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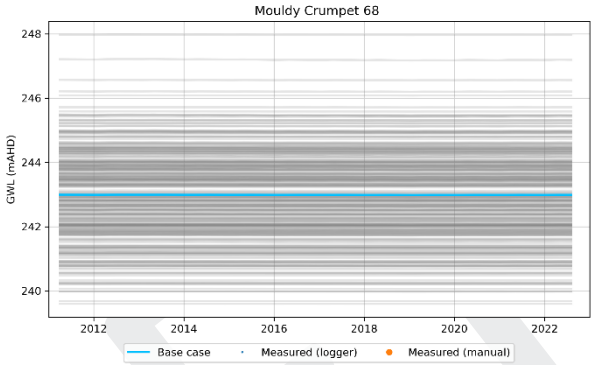
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 68
GWL (mAHD)
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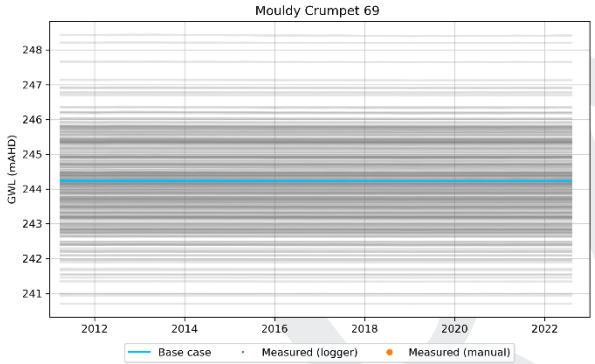
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 69
GWL (mAHD)
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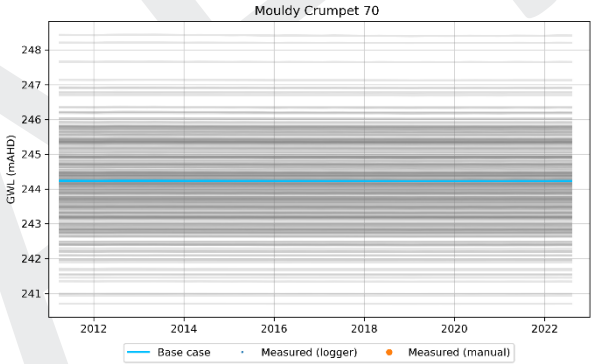
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 70
GWL (mAHD)
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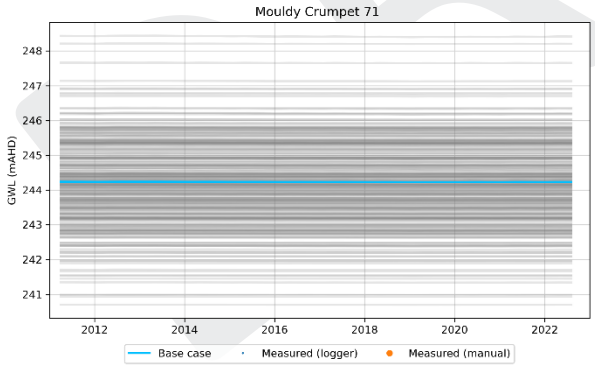
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 71
GWL (mAHD)
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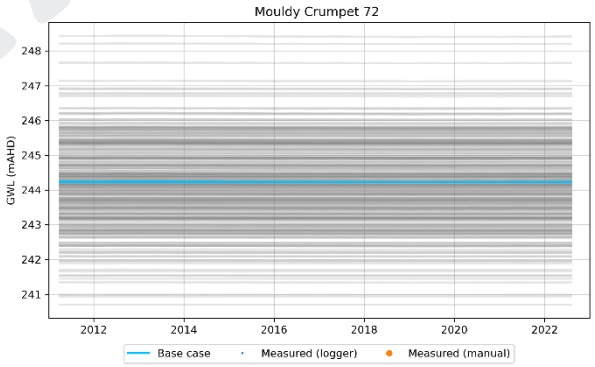
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 72
GWL (mAHD)
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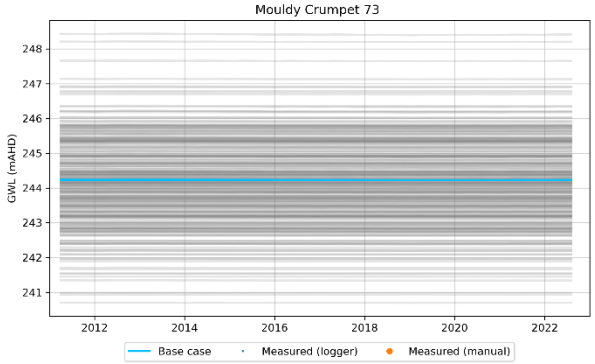
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 73
GWL (mAHD)
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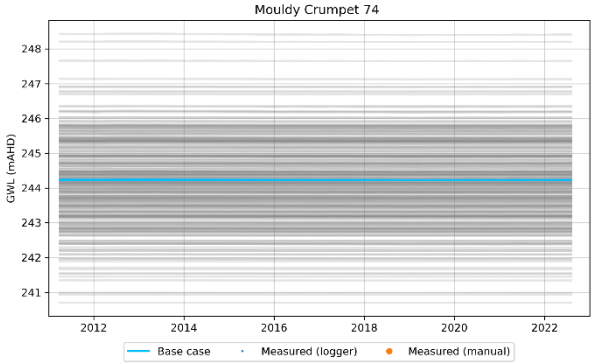
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 74
GWL (mAHD)
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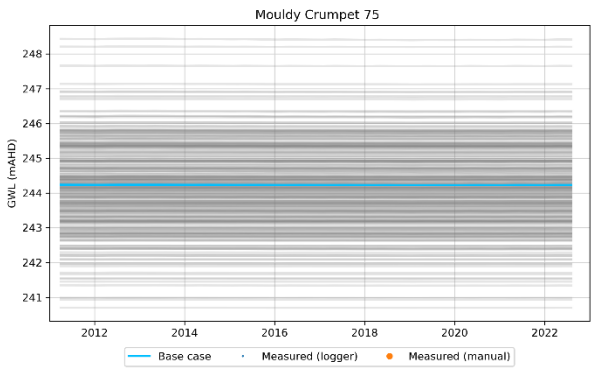
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 75
GWL (mAHD)
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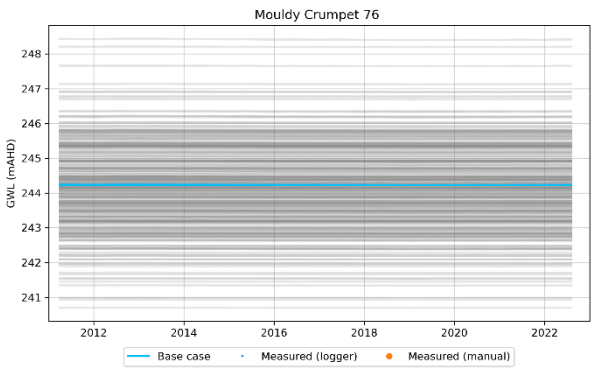
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 76
GWL (mAHD)
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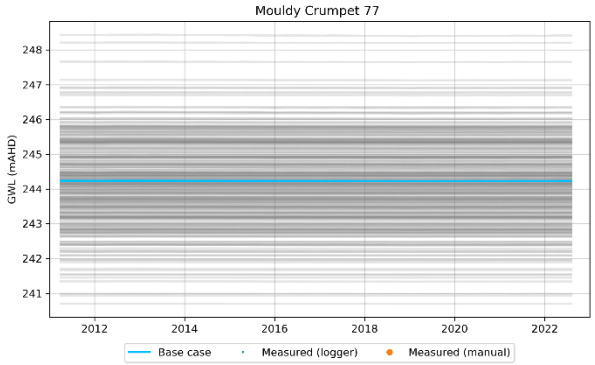
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 77
GWL (mAHD)
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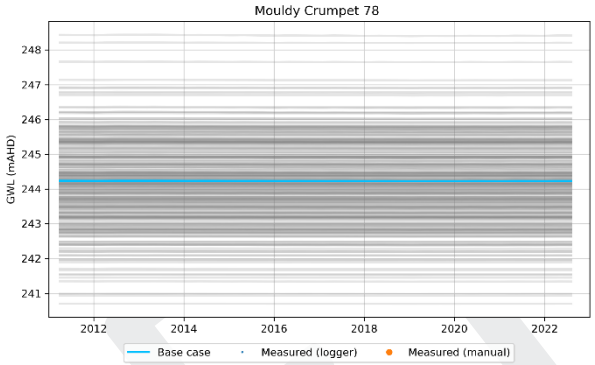
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 78
GWL (mAHD)
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Base case
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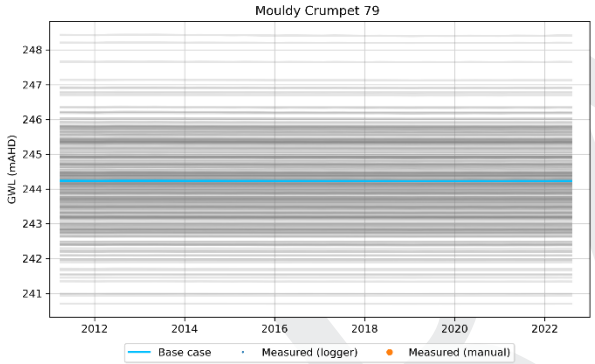
Measured (manual)


Mouldy Crumpet 79
GWL (mAHD)
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Base case
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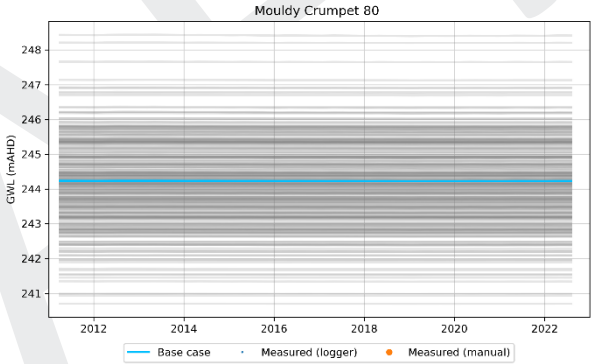
Measured (manual)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GWL (mAHD)
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Base case
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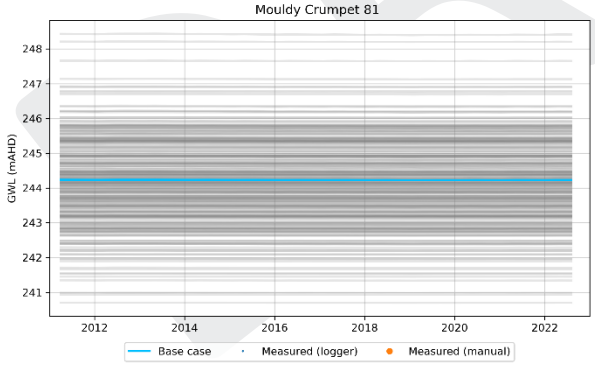
Measured (manual)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GWL (mAHD)
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Base case
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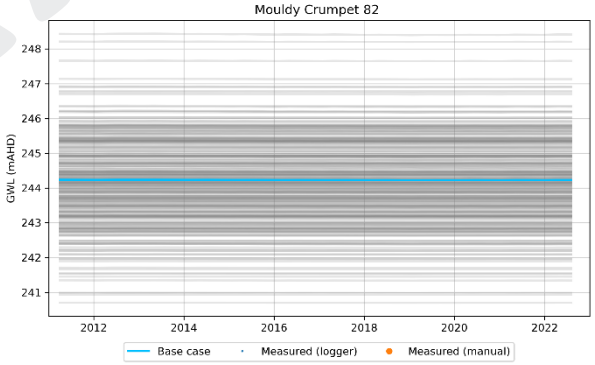
Measured (manual)


Mouldy Crumpet 82
GWL (mAHD)
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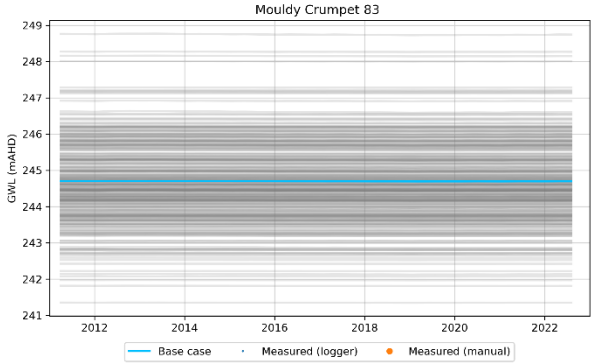
Measured (manual)


Mouldy Crumpet 83
GWL (mAHD)
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Base case
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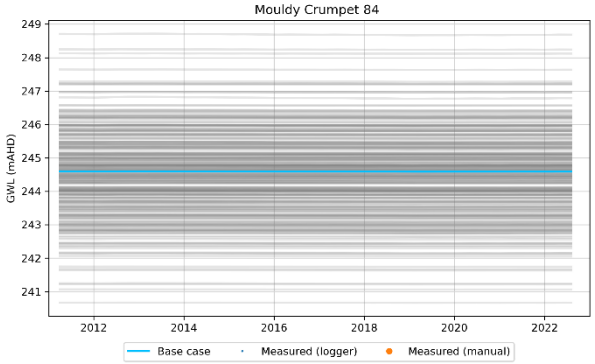
Measured (manual)


Mouldy Crumpet 84
GWL (mAHD)
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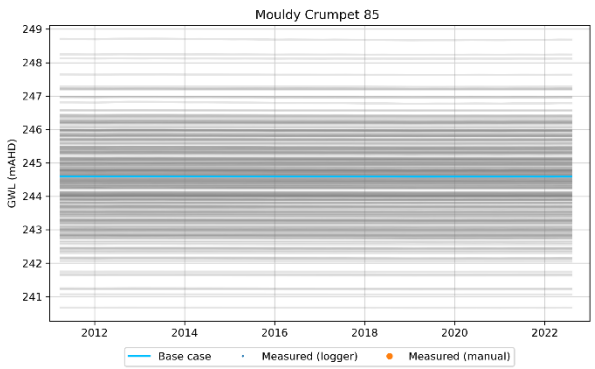
Measured (logger)
Measured (manual)


Mouldy Crumpet 85
GWL (mAHD)
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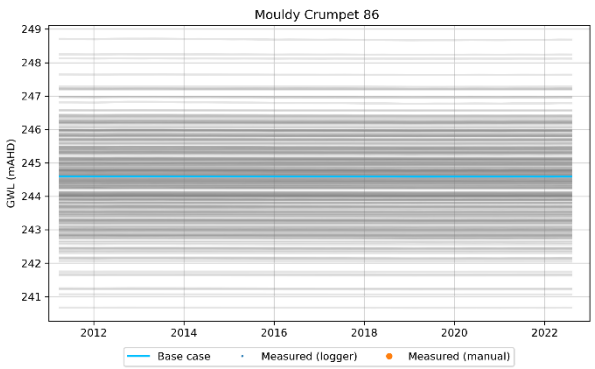
Measured (manual)


Mouldy Crumpet 86
GWL (mAHD)
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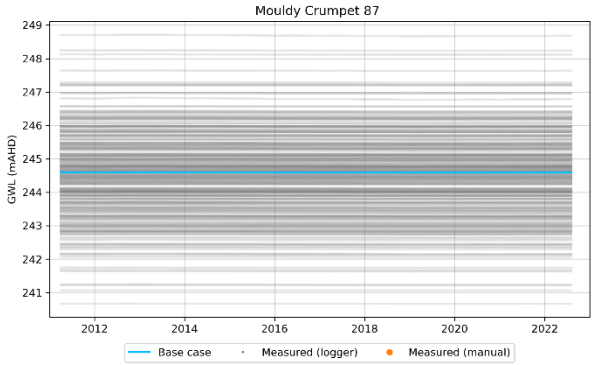
Mouldy Crumpet 87
GWL (mAHD)
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Base case
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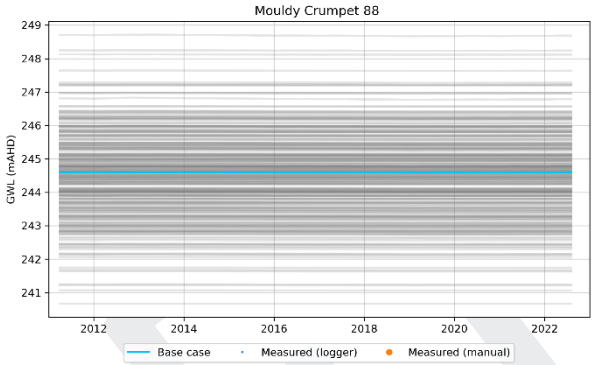
Measured (manual)


Mouldy Crumpet 88
GWL (mAHD)
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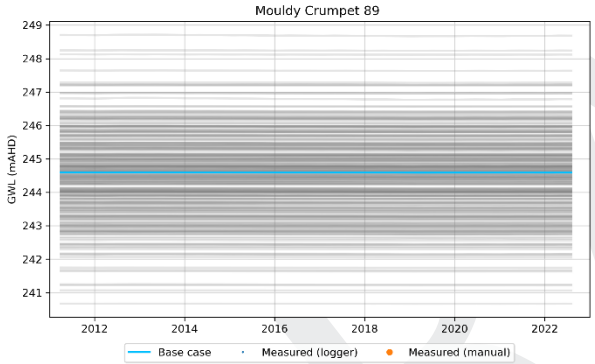
Measured (manual)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GWL (mAHD)
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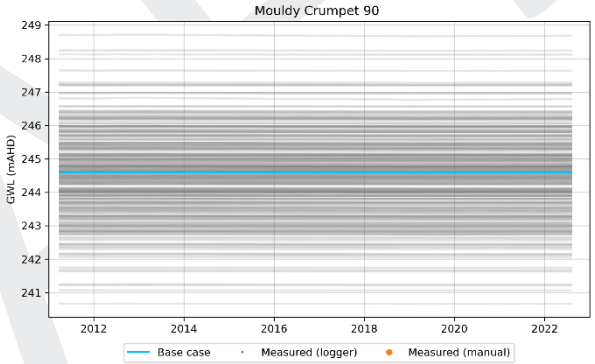
Measured (manual)


Mouldy Crumpet 90
GWL (mAHD)
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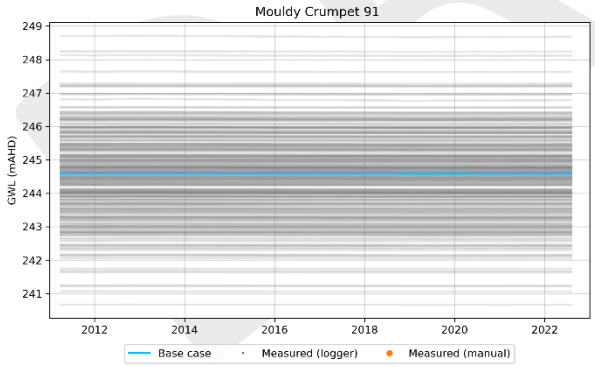
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GWL (mAHD)
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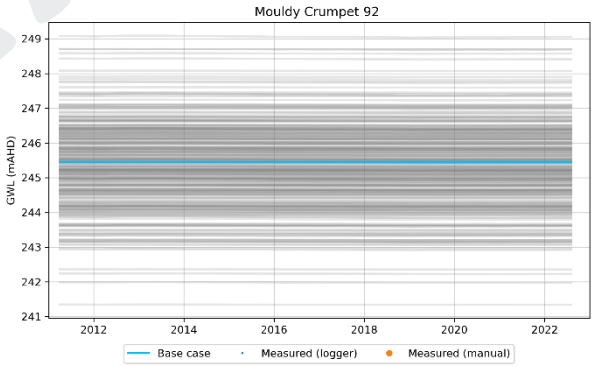
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GWL (mAHD)
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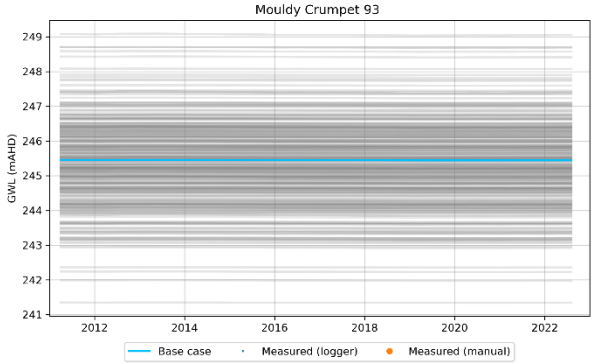
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GWL (mAHD)
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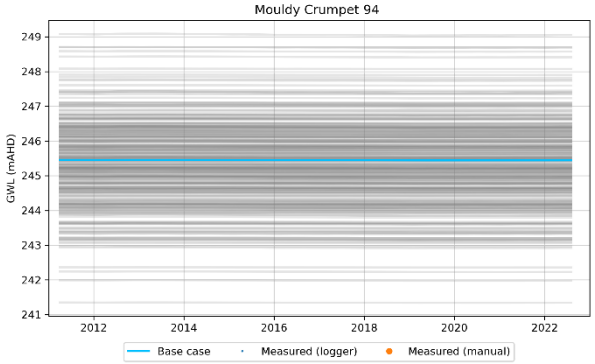
Mouldy Crumpet 94
GWL (mAHD)
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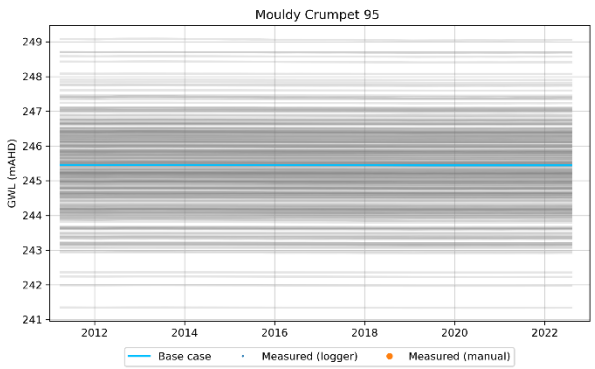
Mouldy Crumpet 95
GWL (mAHD)
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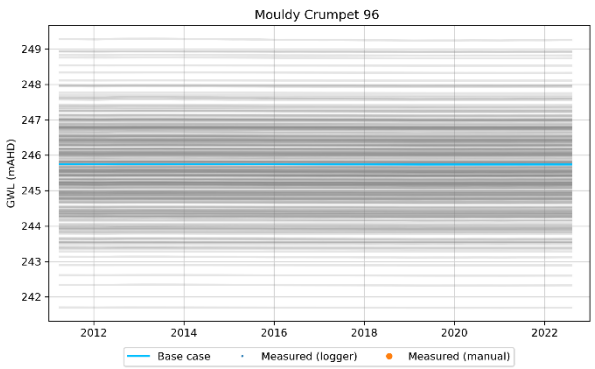
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GWL (mAHD)
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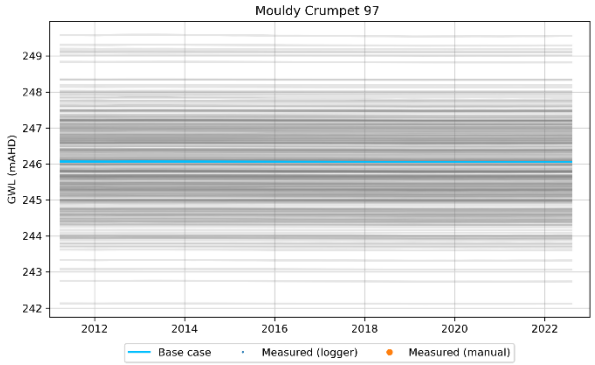
Mouldy Crumpet 97
GWL (mAHD)
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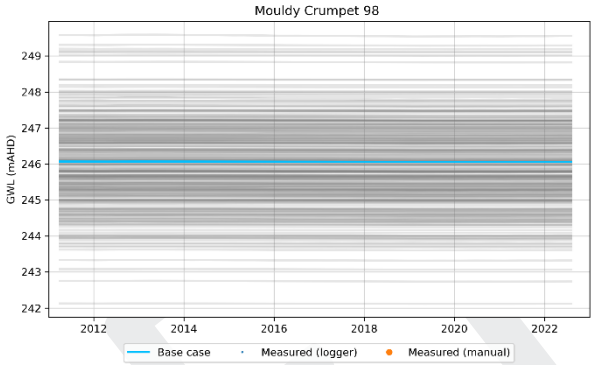
Measured (manual)


Mouldy Crumpet 98
GWL (mAHD)
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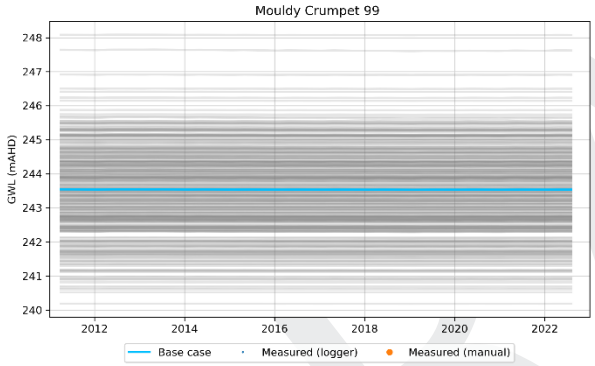
Measured (logger)
Measured (manual)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GWL (mAHD)
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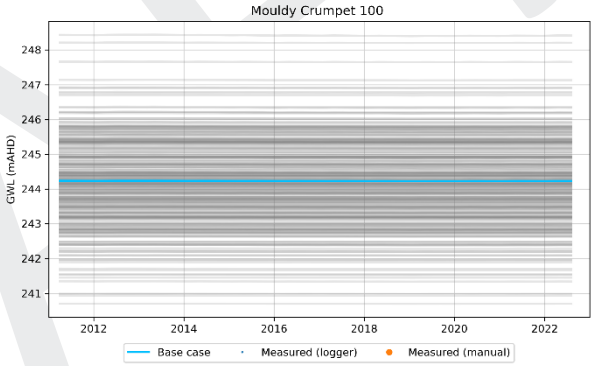
Measured (manual)


Mouldy Crumpet 100
GWL (mAHD)
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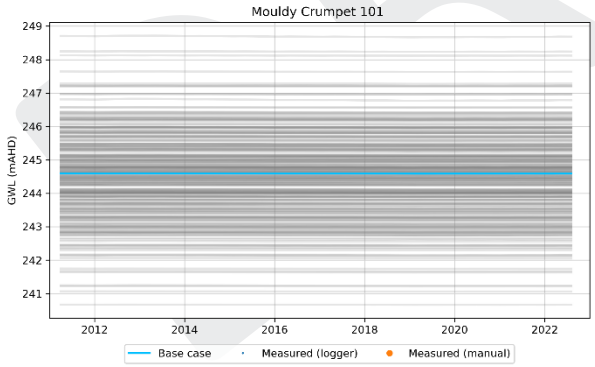
Measured (manual)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GWL (mAHD)
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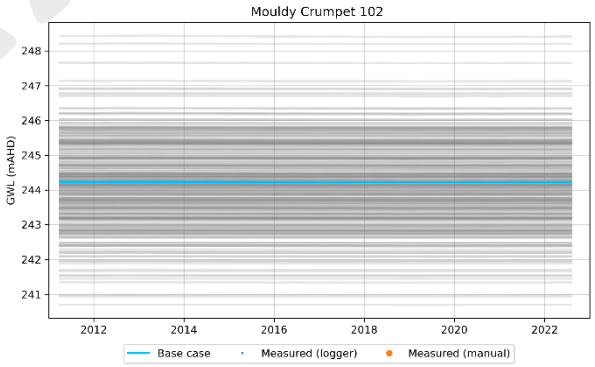
Mouldy Crumpet 102
GWL (mAHD)
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Base case
Measured (logger)
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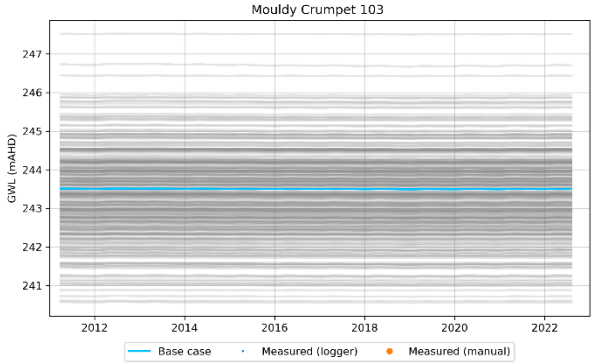
Mouldy Crumpet 103
GWL (mAHD)
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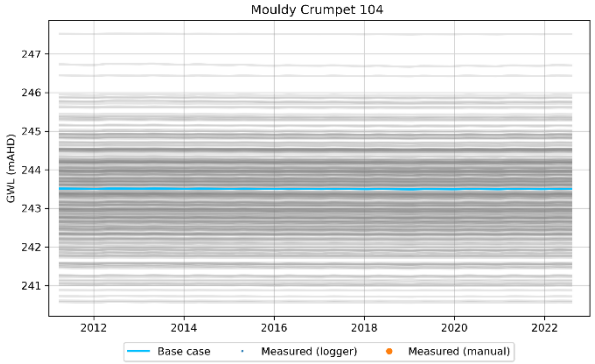
Measured (manual)


Mouldy Crumpet 104
GWL (mAHD)
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Base case
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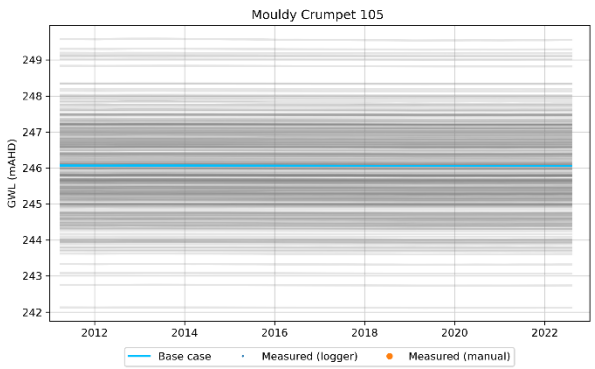
Measured (manual)


Mouldy Crumpet 105
GWL (mAHD)
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Base case
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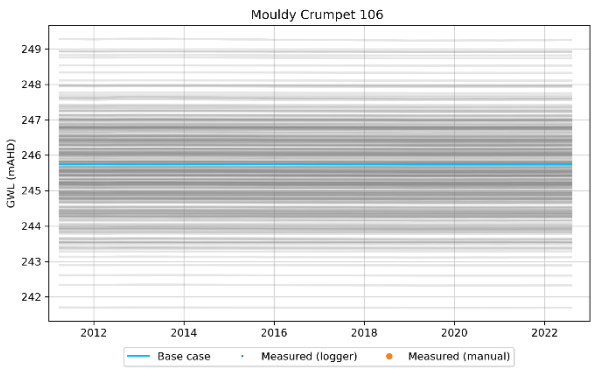
Measured (manual)


Mouldy Crumpet 106
GWL (mAHD)
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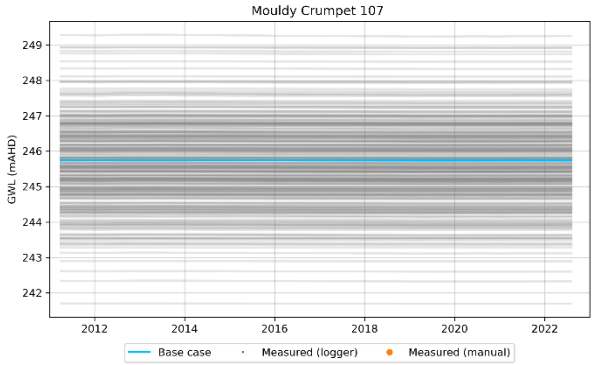
Base case
Measured (logger)
Measured (manual)


Mouldy Crumpet 107
GWL (mAHD)
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Base case
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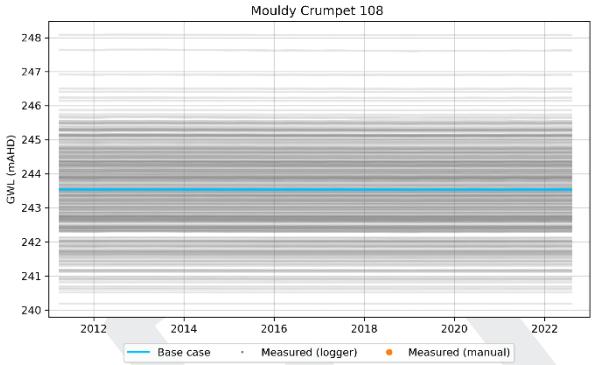
Measured (manual)


Mouldy Crumpet 108
GWL (mAHD)
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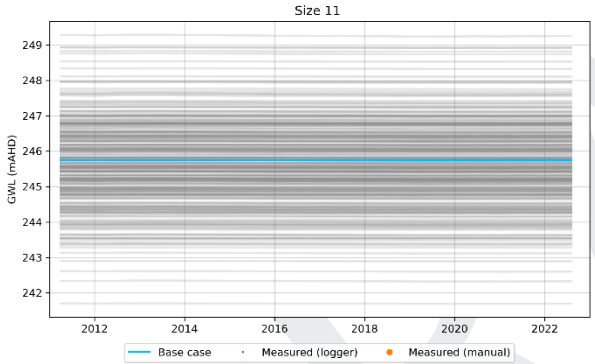
Measured (manual)


Size 11
GWL (mAHD)
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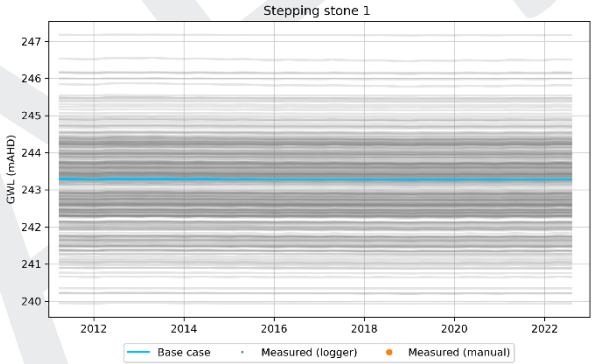
Base case
Measured (logger)
Measured (manual)


Stepping stone 1
GWL (mAHD)
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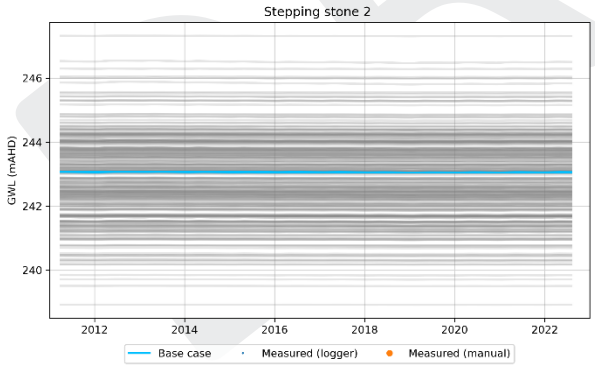
Base case
Measured (logger)
Measured (manual)


Stepping stone 2
GWL (mAHD)
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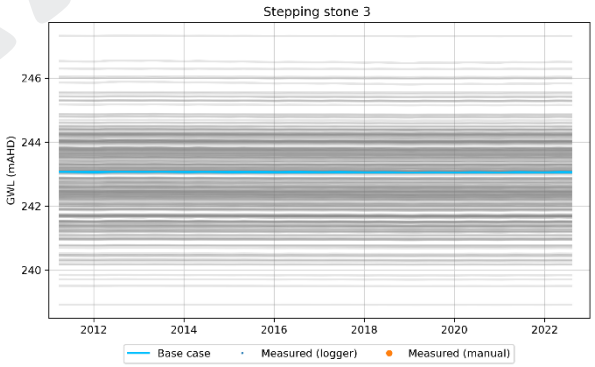
Base case
Measured (logger)
Measured (manual)


Stepping stone 3
GWL (mAHD)
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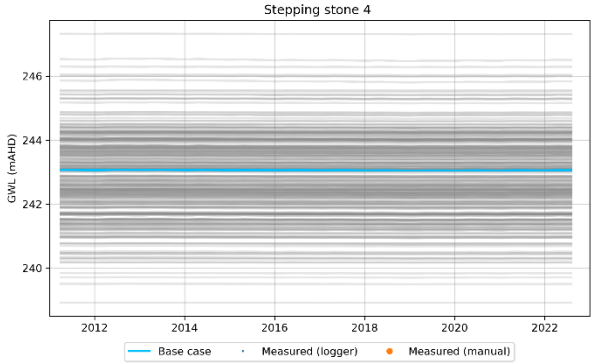
Base case
Measured (logger)
Measured (manual)


Stepping stone 4
GWL (mAHD)
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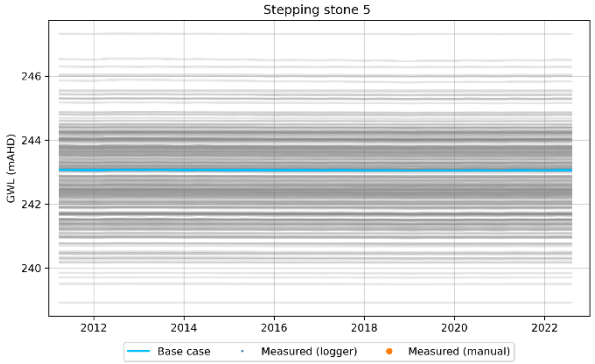
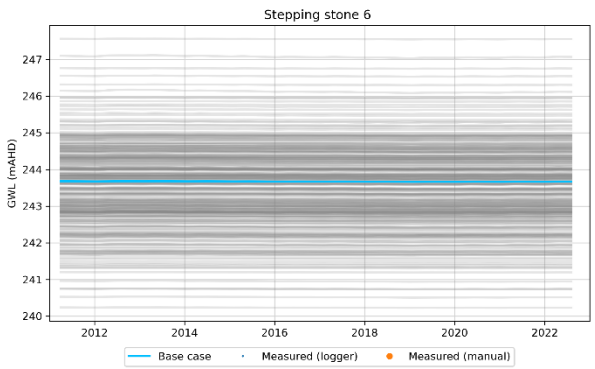
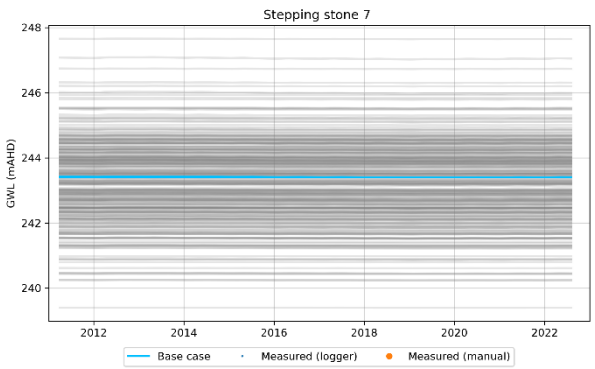
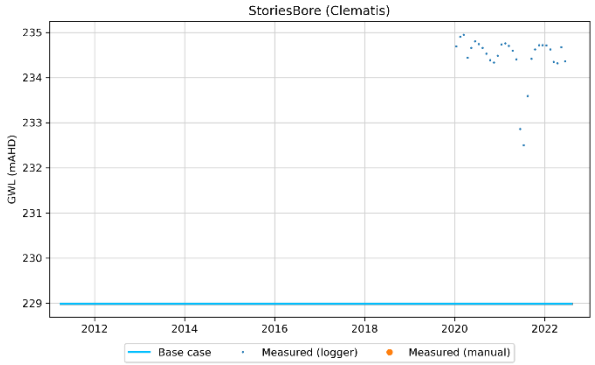
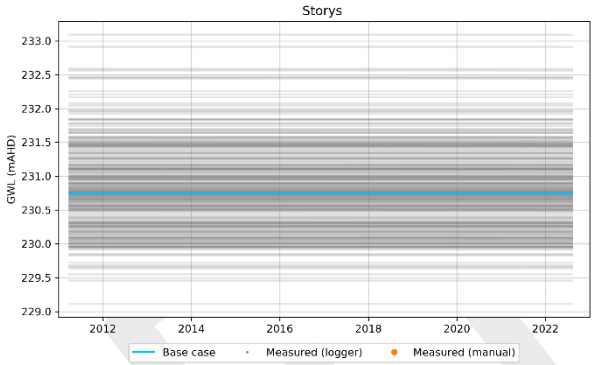
Base case
Measured (logger)
Measured (manual)

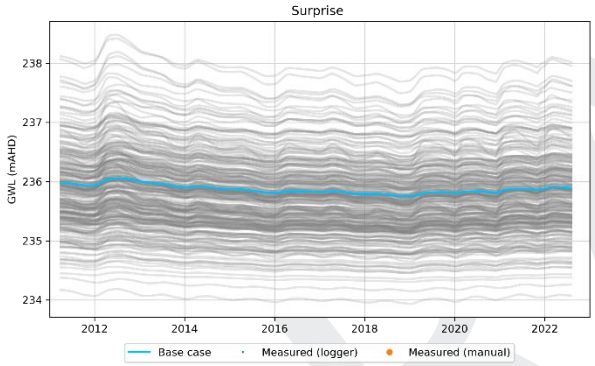

Stepping stone 5
GWL (mAHD)
246
244
242
240
2012
2014
2016
2018
2020
2022
Base case
Measured (logger)
Measured (manual)

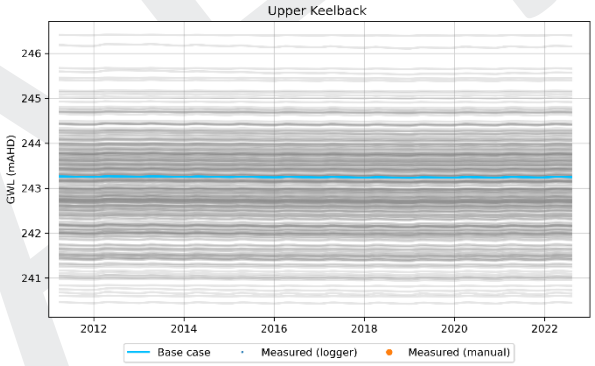

Stepping stone 6
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

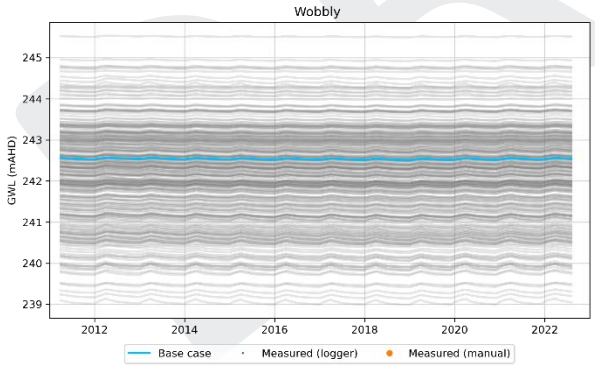

Stepping stone 7
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

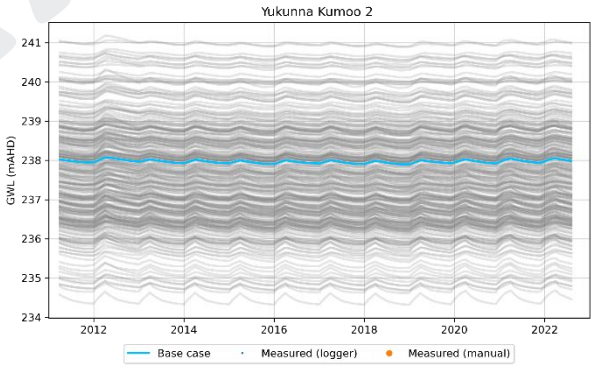

StoriesBore (Clematis)
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

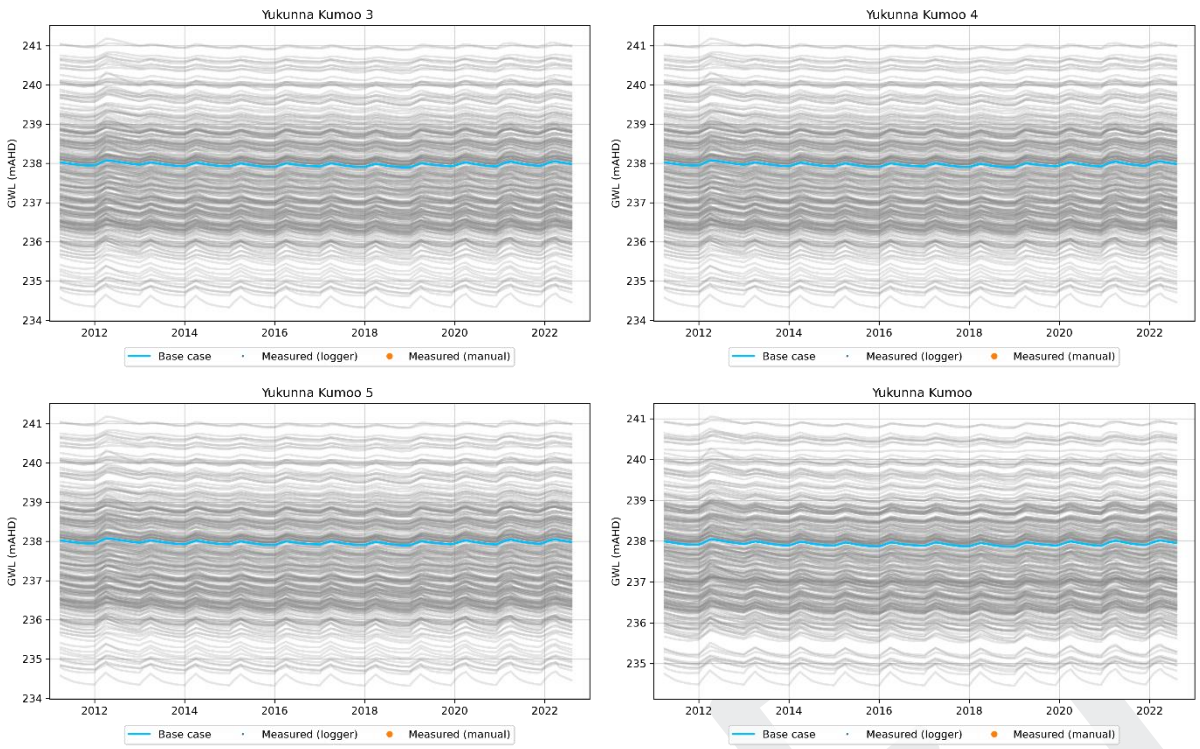

Storys
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


Surprise
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


Upper Keelback
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


Wobbly
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)


Yukunna Kumoo 2
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

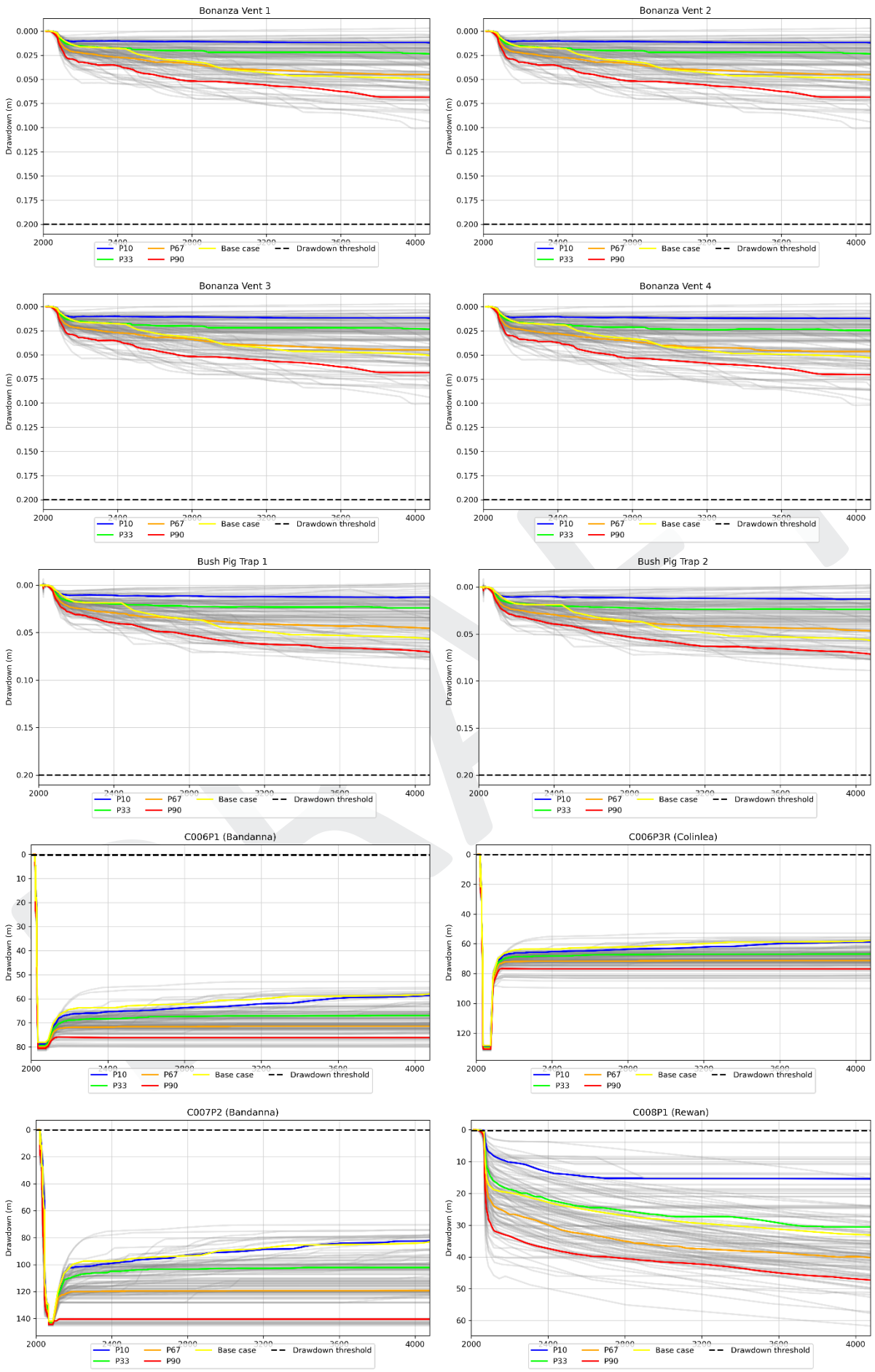

Yukunna Kumoo 3
Yukunna Kumoo 4
Yukunna Kumoo 5
Yukunna Kumoo
GWL (mAHD)
Base case
Measured (logger)
Measured (manual)

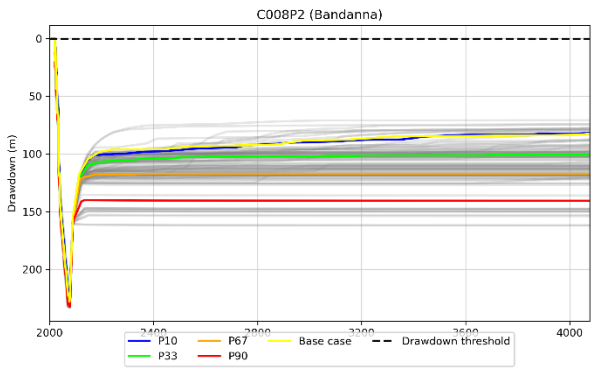
DRAFT

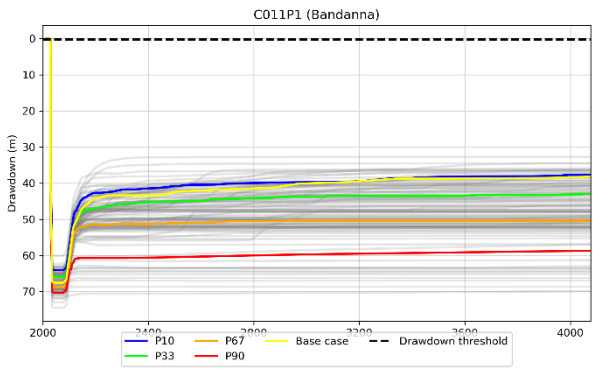
Appendix D

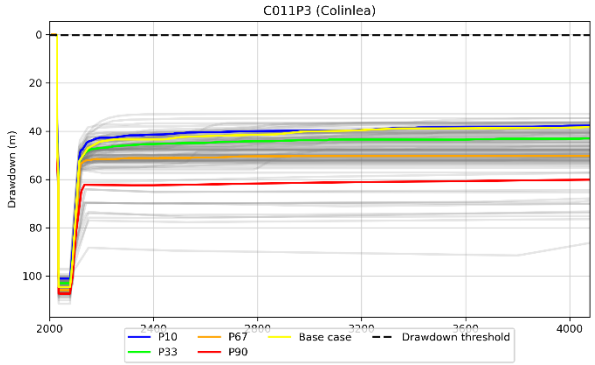
Hydrographs: open cut only

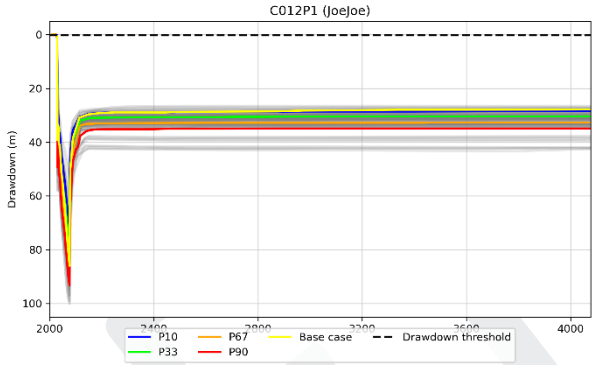
EMM
creating opportunities

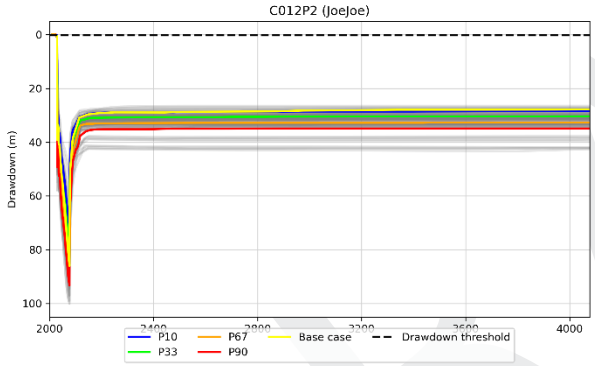

Bonanza Vent 1
Bonanza Vent 2
Bonanza Vent 3
Bonanza Vent 4
Bush Pig Trap 1
Bush Pig Trap 2
C006P1 (Bandanna)
C006P3R (Colinlea)
C007P2 (Bandanna)
C008P1 (Rewan)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

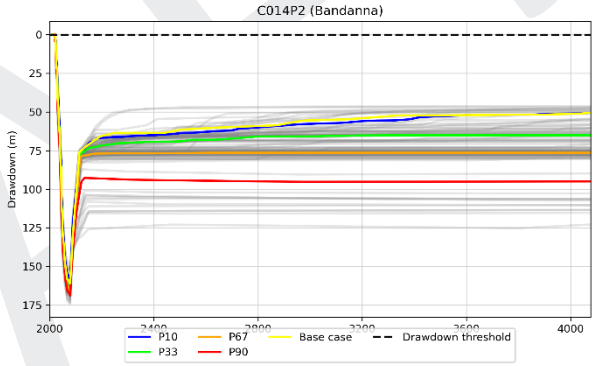

C008P2 (Bandanna)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

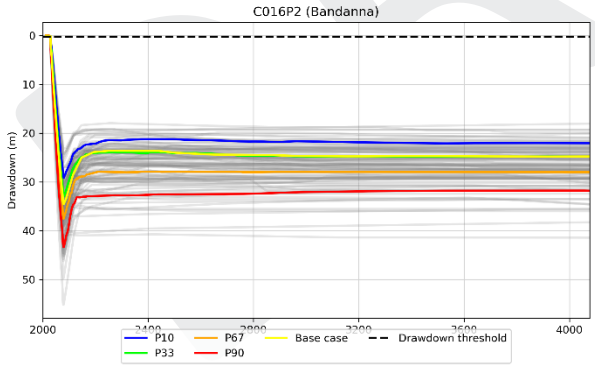

C011P1 (Bandanna)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

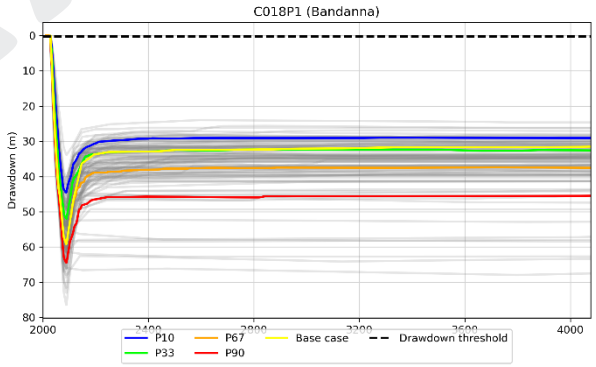

C011P3 (Colinlea)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

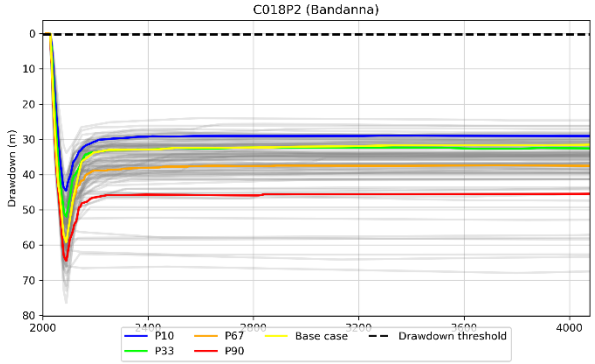

C012P1 (JoeJoe)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

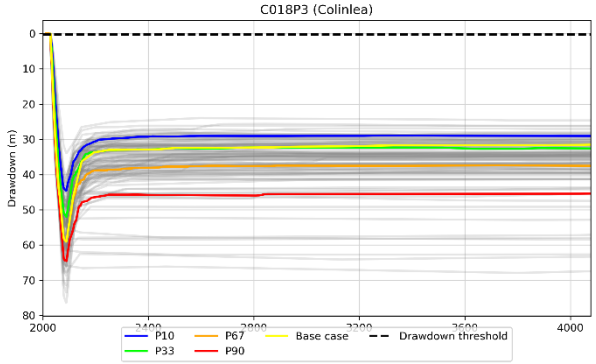

C012P2 (JoeJoe)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

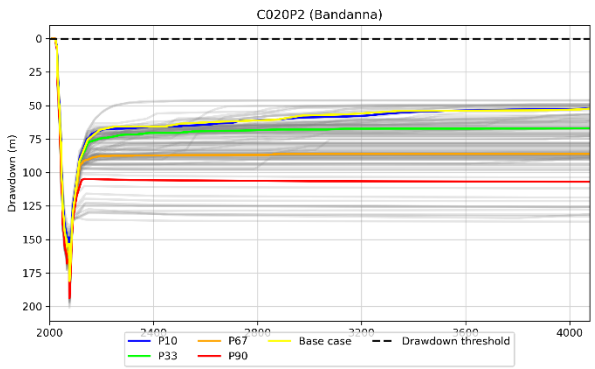

C014P2 (Bandanna)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

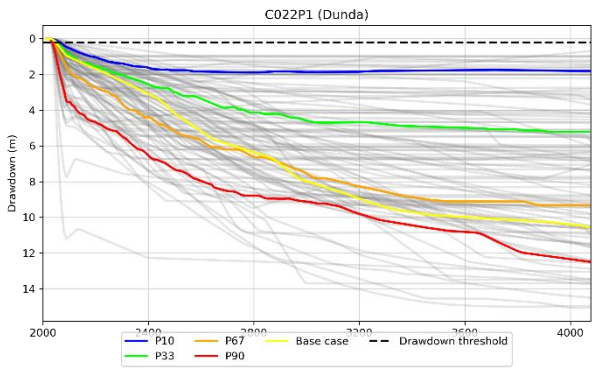

C016P2 (Bandanna)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

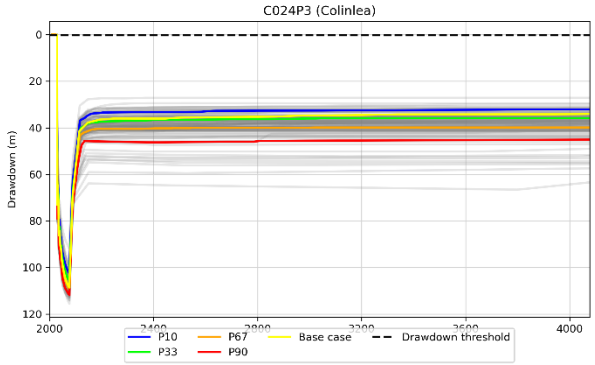

C018P1 (Bandanna)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

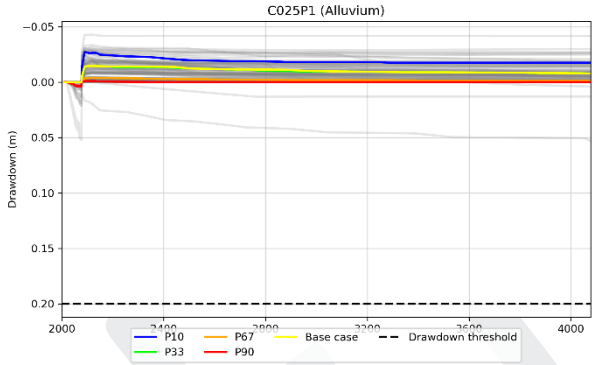

C018P2 (Bandanna)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

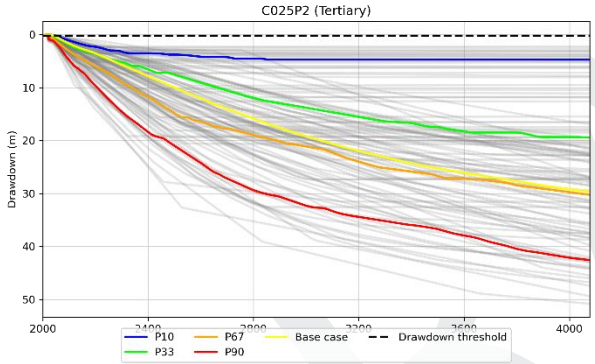

C018P3 (Colinlea)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

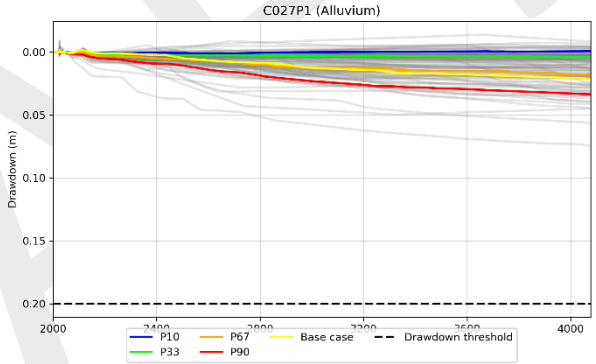

C020P2 (Bandanna)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

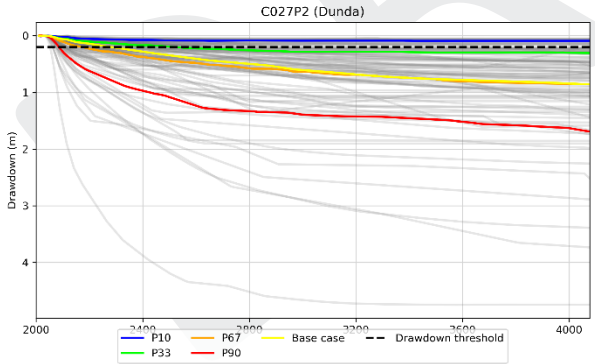

C022P1 (Dunda)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

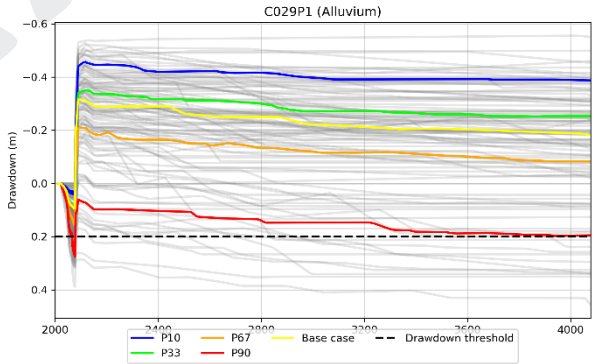

C024P3 (Colinlea)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

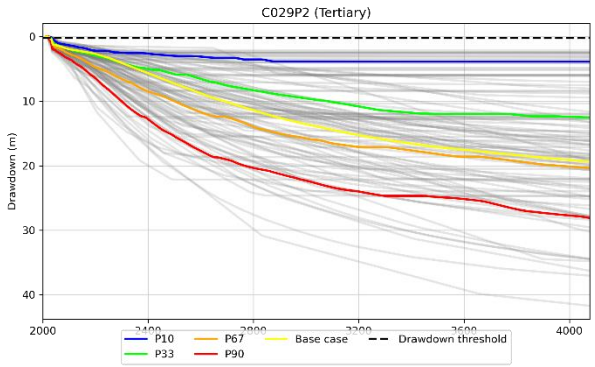

C025P1 (Alluvium)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

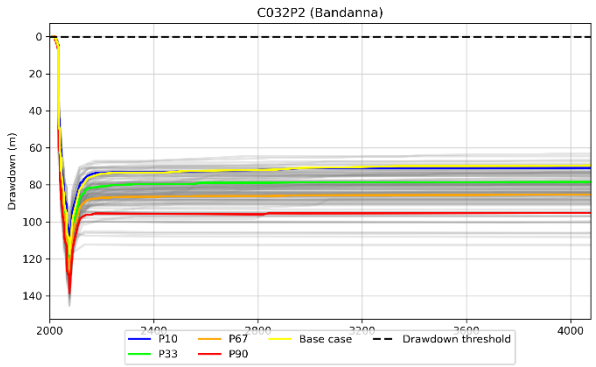

C025P2 (Tertiary)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

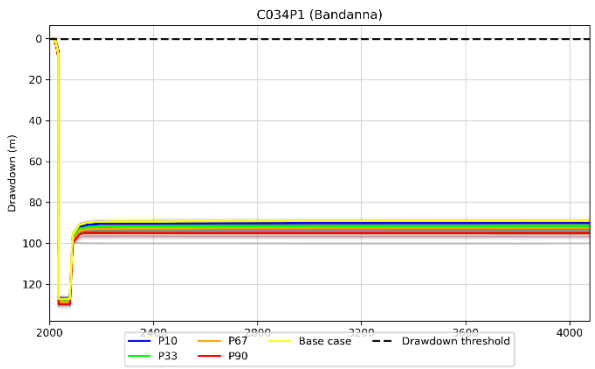

C027P1 (Alluvium)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

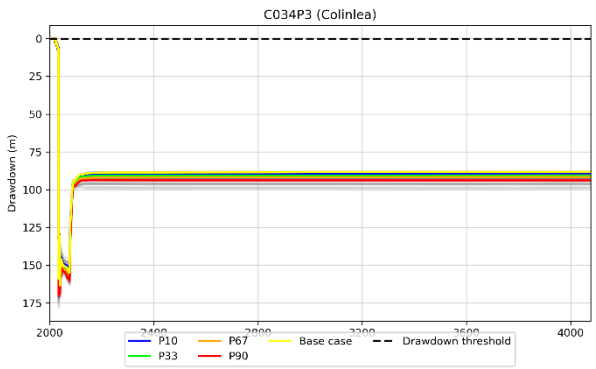

C027P2 (Dunda)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

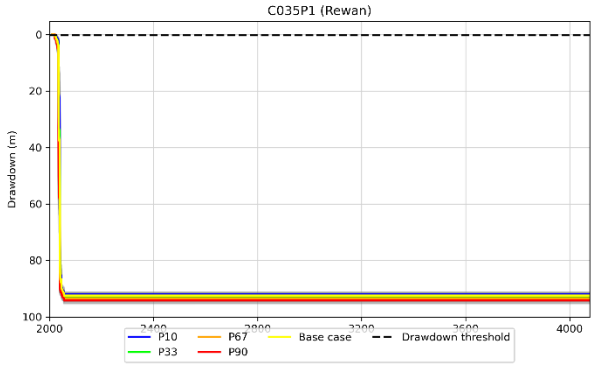

C029P1 (Alluvium)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

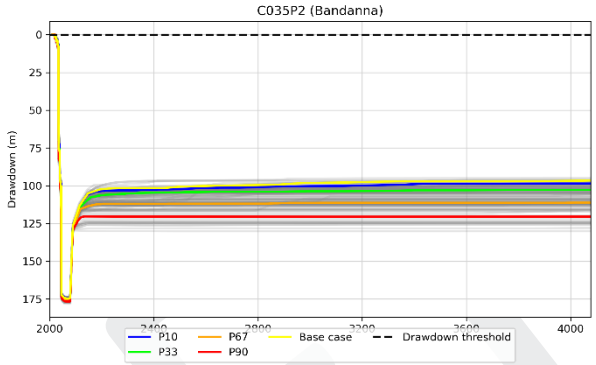

C029P2 (Tertiary)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

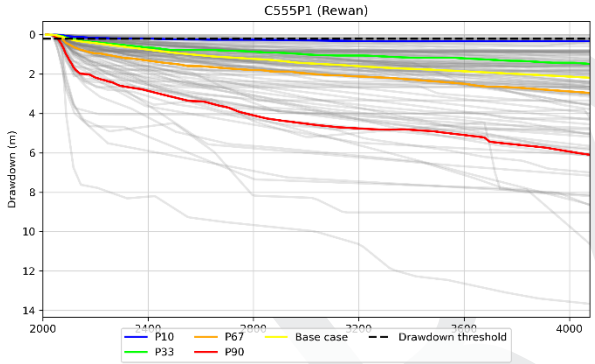

C032P2 (Bandanna)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

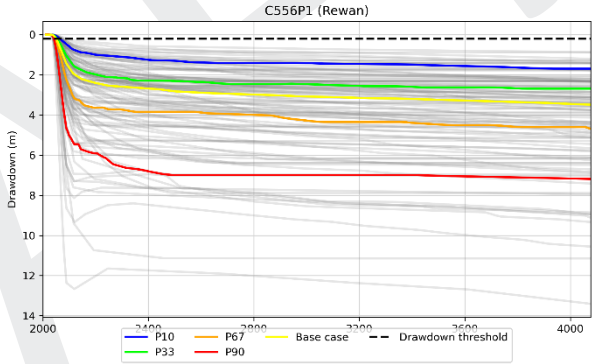

C034P1 (Bandanna)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

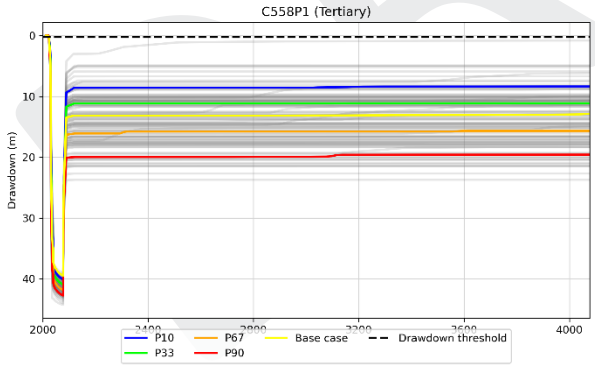

C034P3 (Colinlea)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

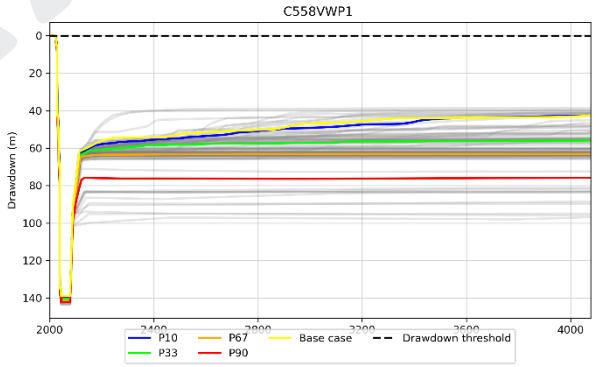

C035P1 (Rewan)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

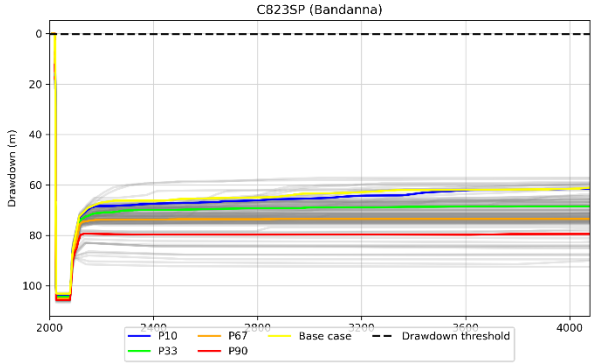

C035P2 (Bandanna)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

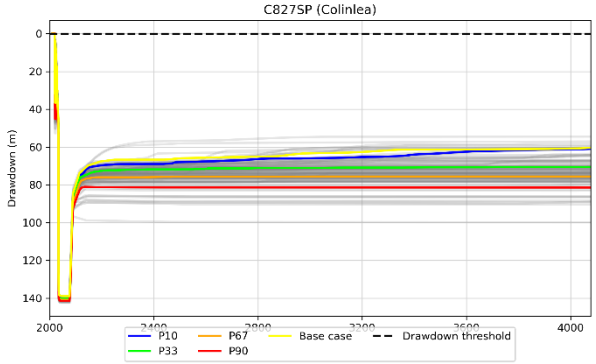

C555P1 (Rewan)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

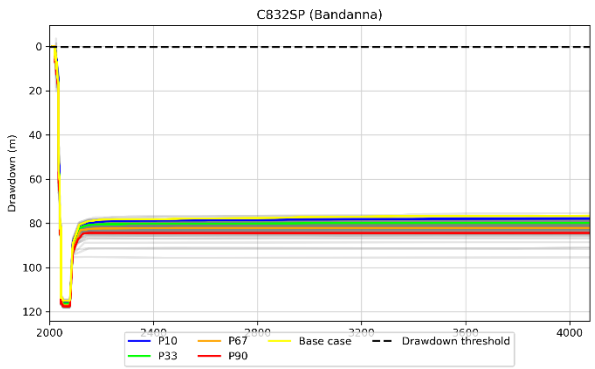

C556P1 (Rewan)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

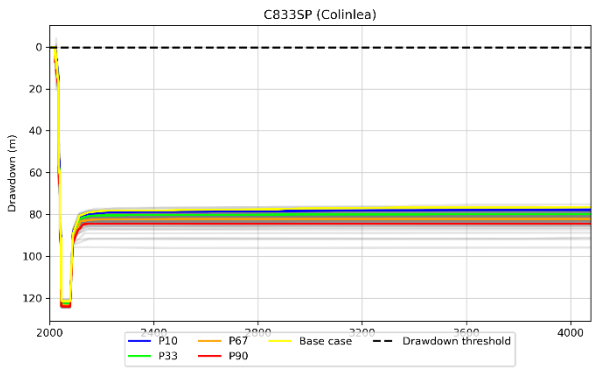

C558P1 (Tertiary)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

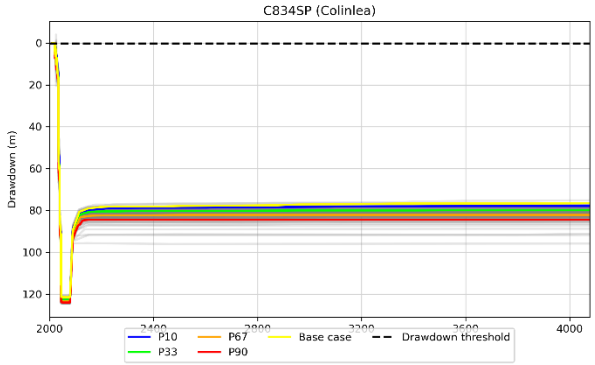

C558VWP1
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

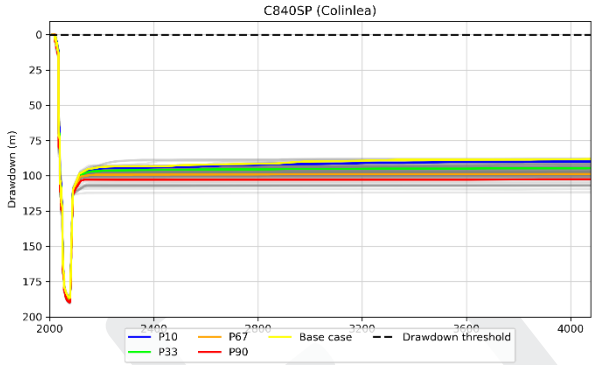

C823SP (Bandanna)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

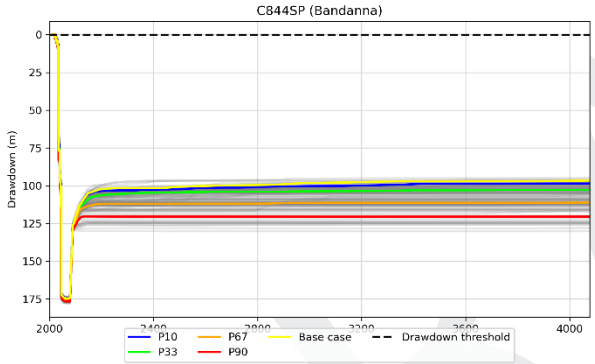

C827SP (Colinlea)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

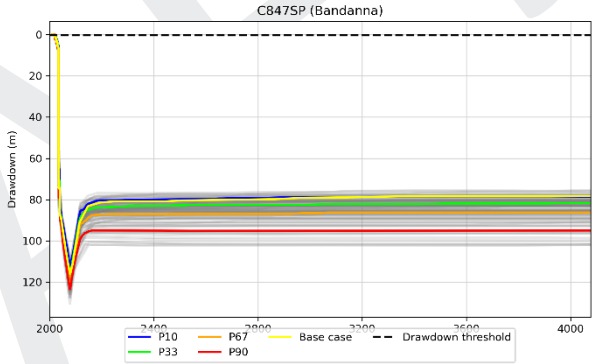

C832SP (Bandanna)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

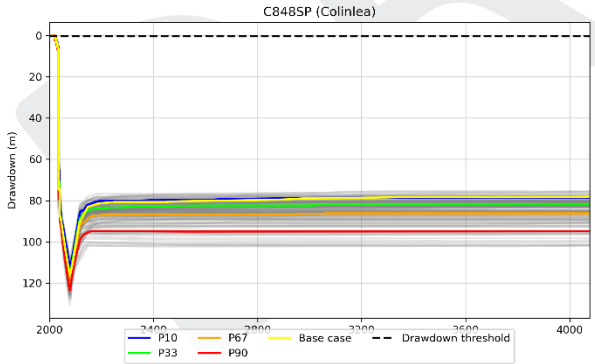

C833SP (Colinlea)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

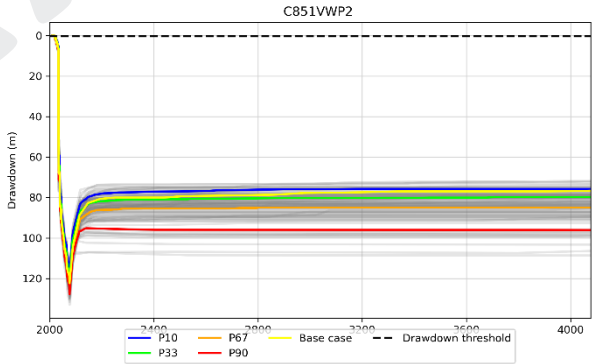

C834SP (Colinlea)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

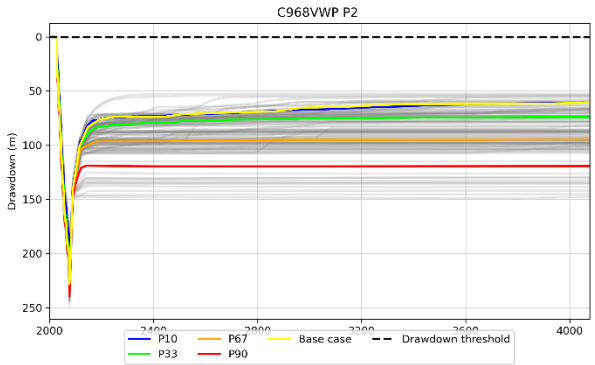

C840SP (Colinlea)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

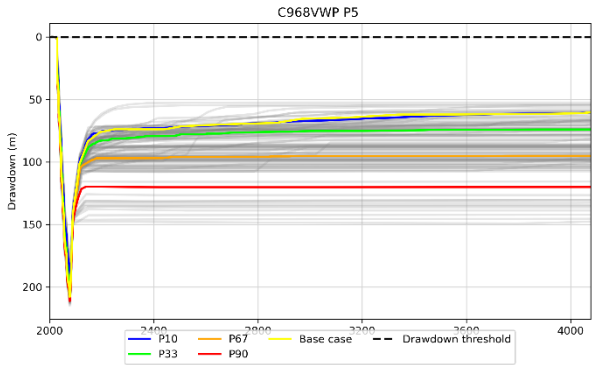

C844SP (Bandanna)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

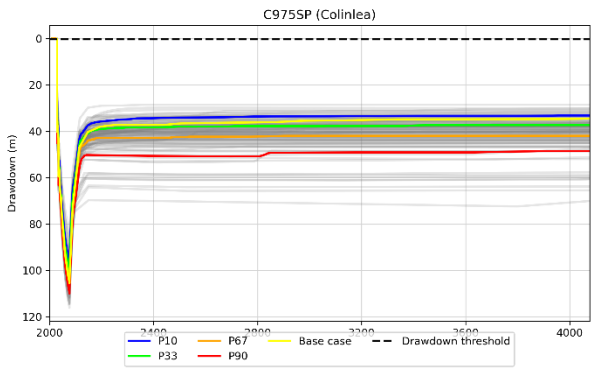

C847SP (Bandanna)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

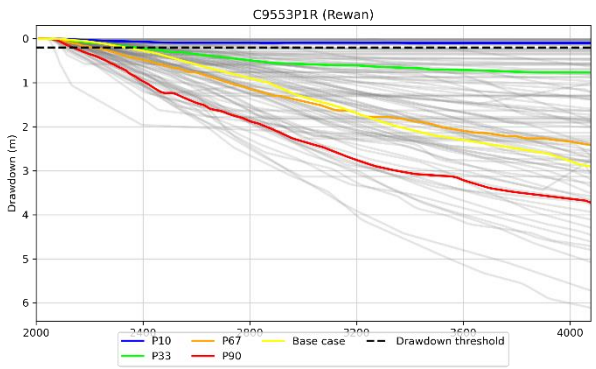

C848SP (Colinlea)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

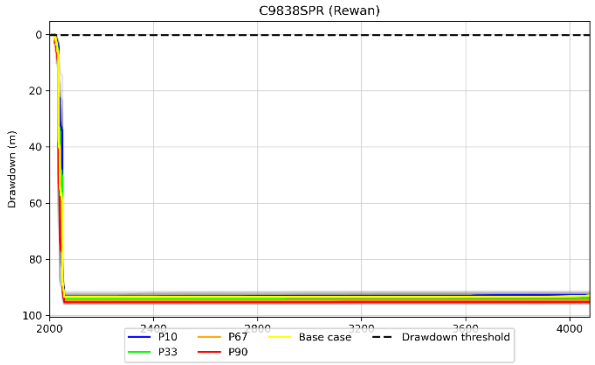

C851VWP2
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

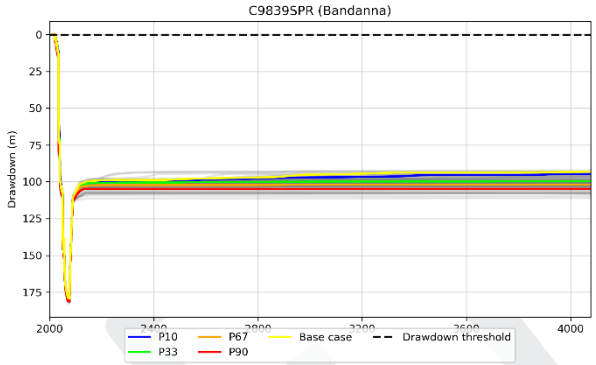

C968VWP P2
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

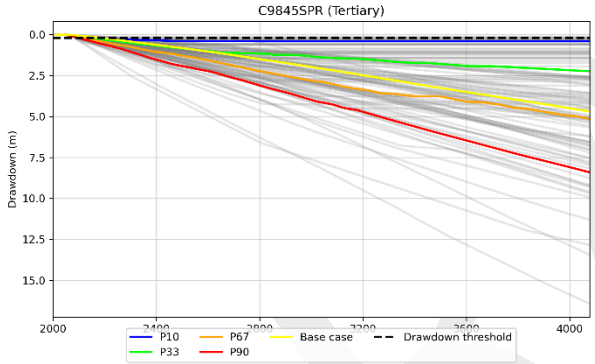

C968VWP P5
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

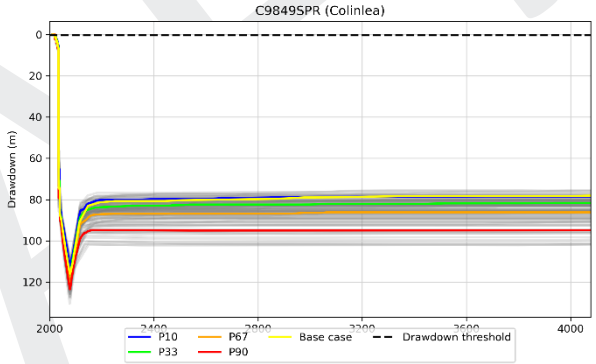

C975SP (Colinlea)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

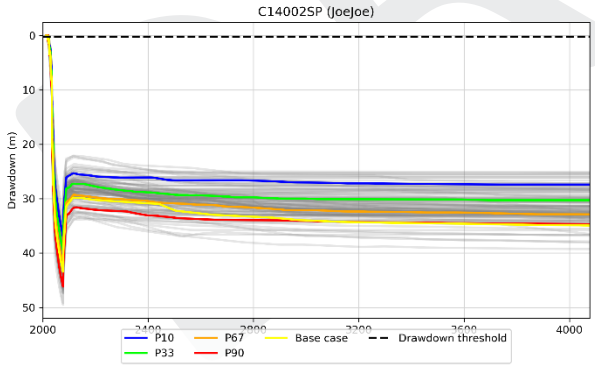

C9553P1R (Rewan)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

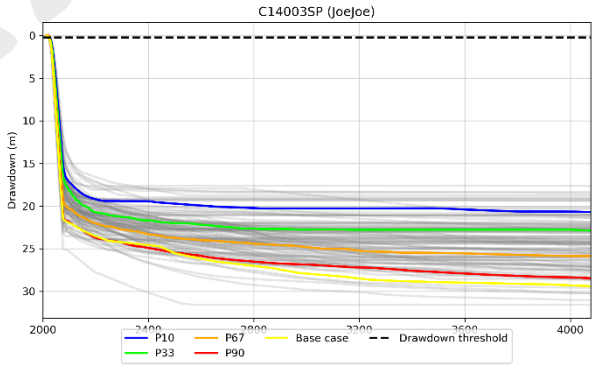

C9838SPR (Rewan)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

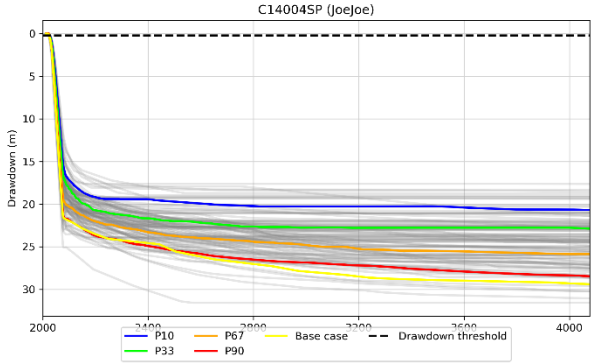

C9839SPR (Bandanna)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

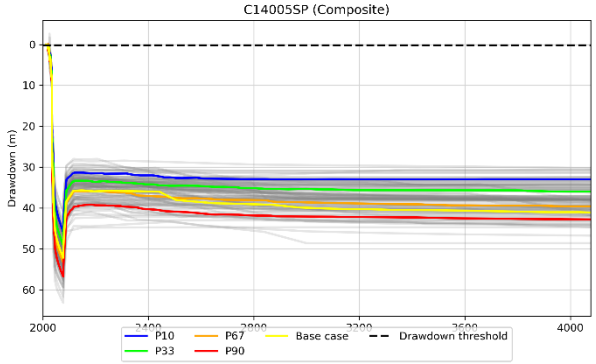

C9845SPR (Tertiary)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

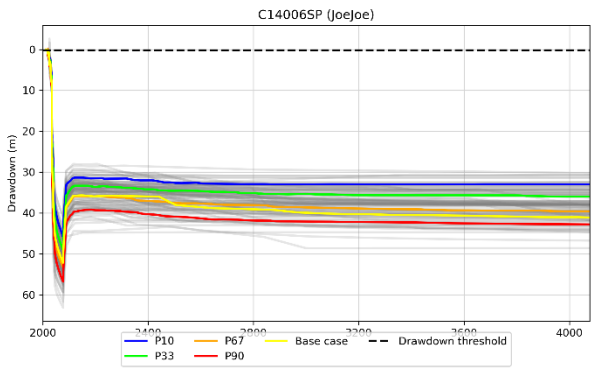

C9849SPR (Colinlea)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

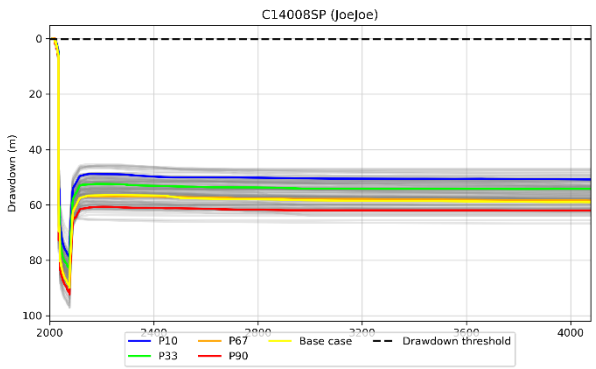

C14002SP (JoeJoe)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

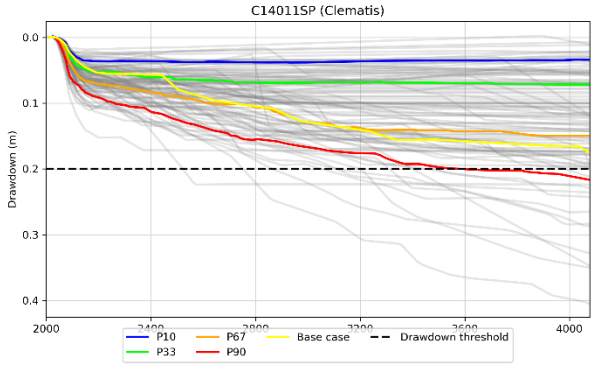

C14003SP (JoeJoe)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

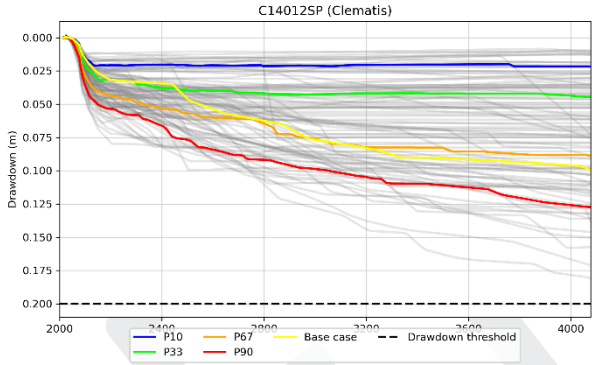

C14004SP (JoeJoe)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

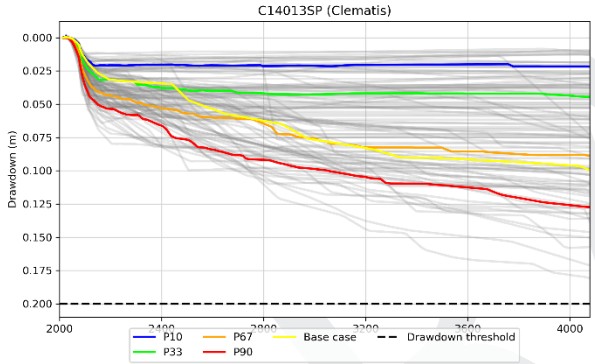

C14005SP (Composite)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

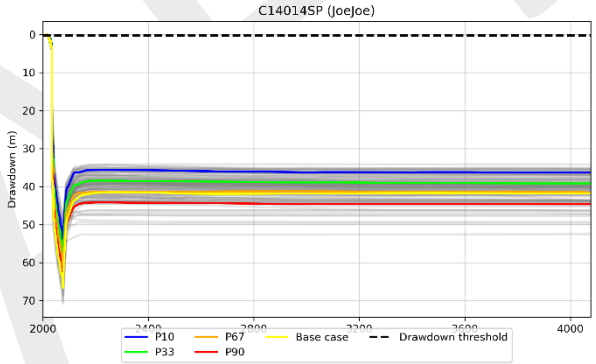

C14006SP (JoeJoe)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

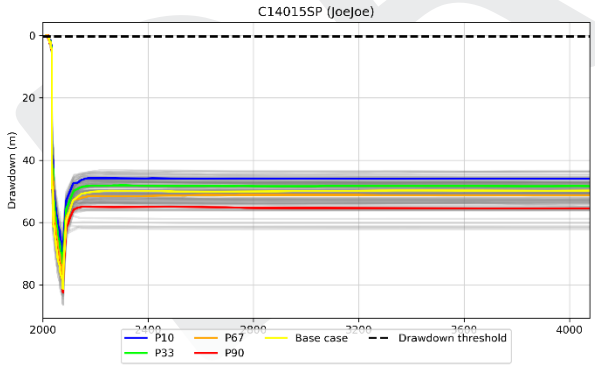

C14008SP (JoeJoe)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

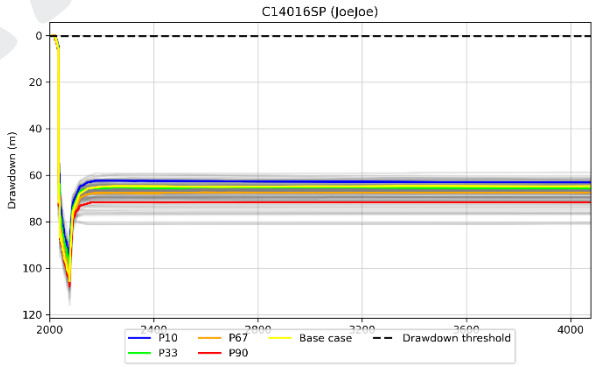

C14011SP (Clematis)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

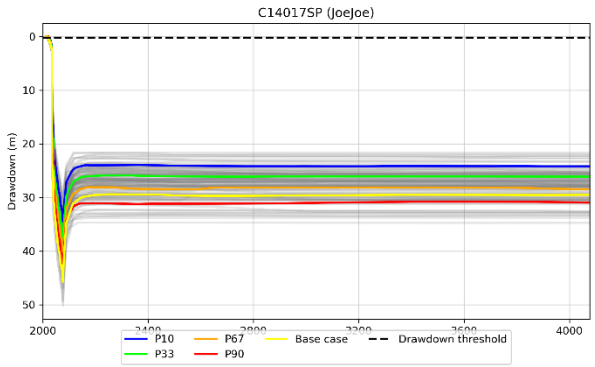

C14012SP (Clematis)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

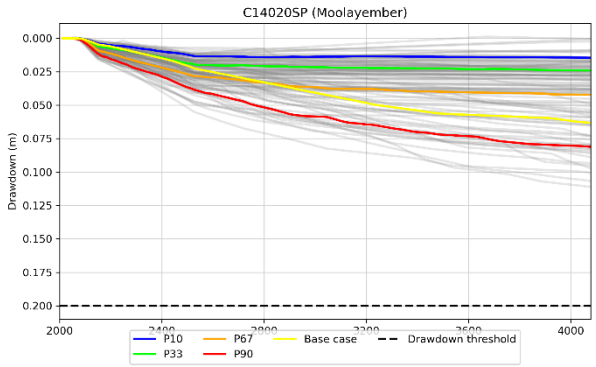

C14013SP (Clematis)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

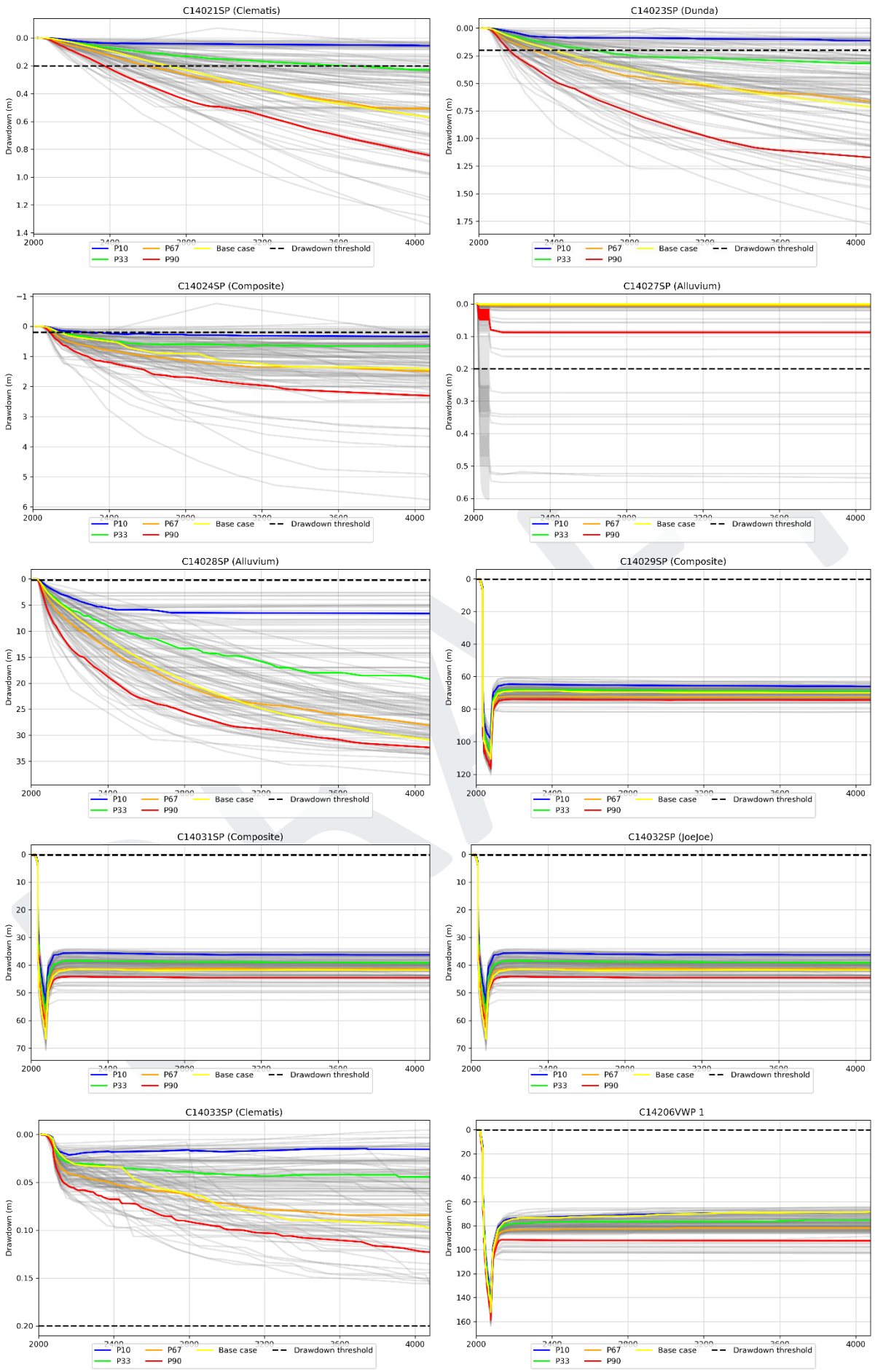

C14014SP (JoeJoe)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

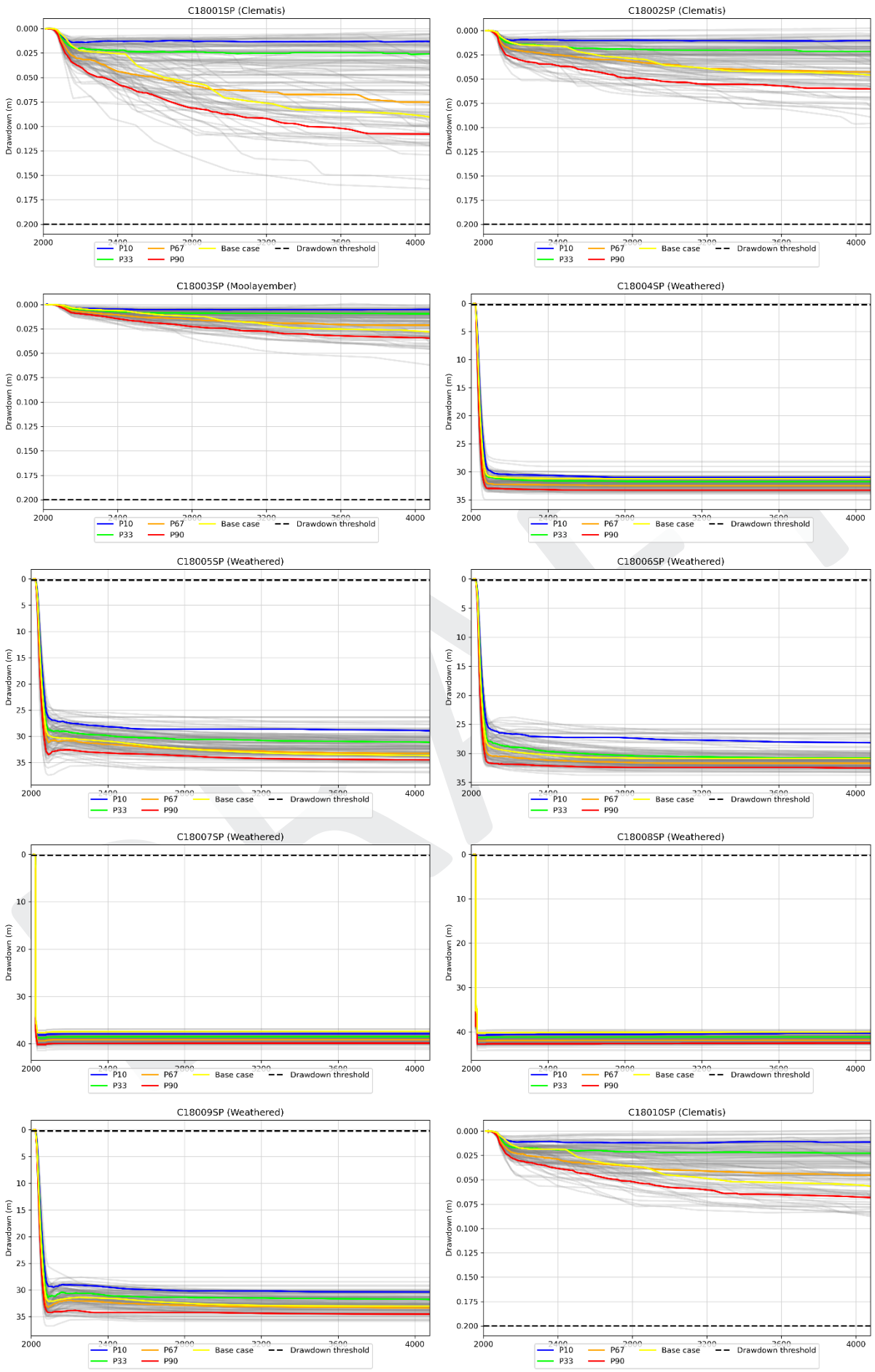

C14015SP (JoeJoe)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

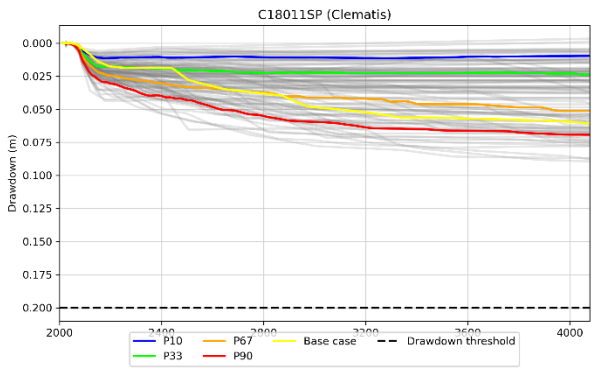

C14016SP (JoeJoe)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

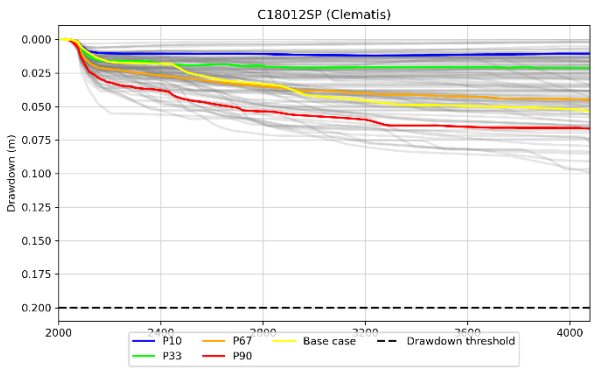

C14017SP (JoeJoe)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

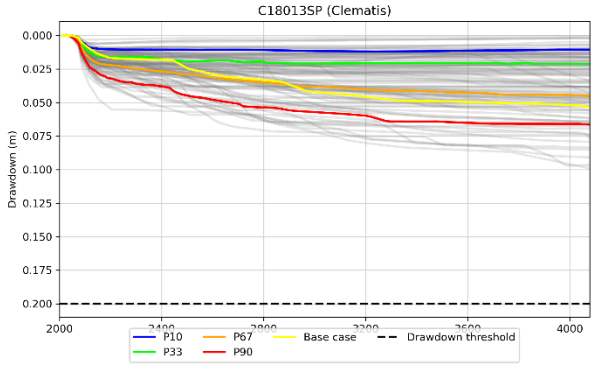

C14020SP (Moolayember)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

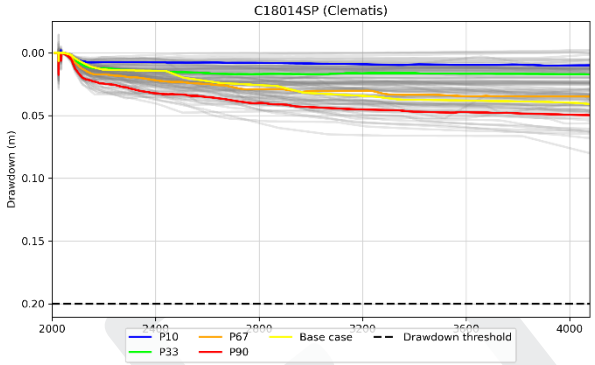

C14021SP (Clematis)
C14023SP (Dunda)
C14024SP (Composite)
C14027SP (Alluvium)
C14028SP (Alluvium)
C14029SP (Composite)
C14031SP (Composite)
C14032SP (JoeJoe)
C14033SP (Clematis)
C14206VWP 1
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

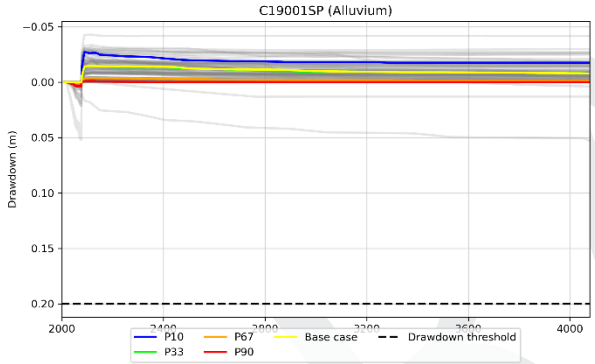

C18001SP (Clematis)
C18002SP (Clematis)
C18003SP (Moolayember)
C18004SP (Weathered)
C18005SP (Weathered)
C18006SP (Weathered)
C18007SP (Weathered)
C18008SP (Weathered)
C18009SP (Weathered)
C18010SP (Clematis)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

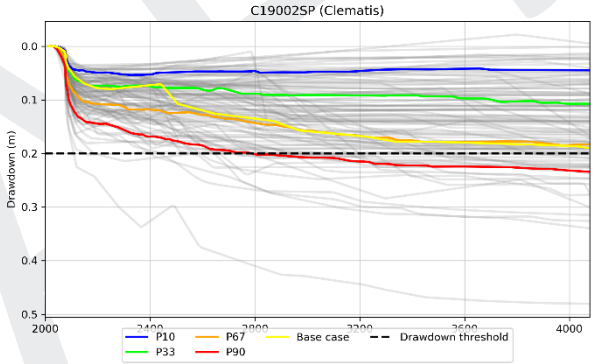

C18011SP (Clematis)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

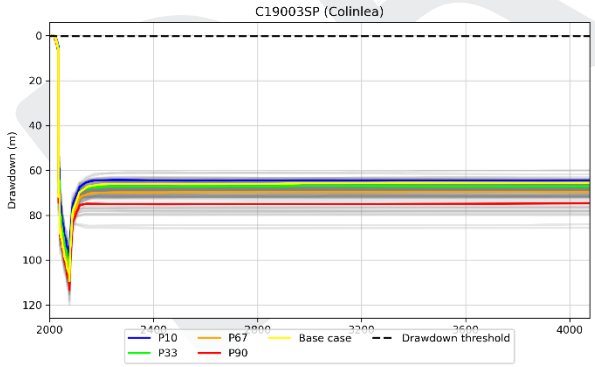

C18012SP (Clematis)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

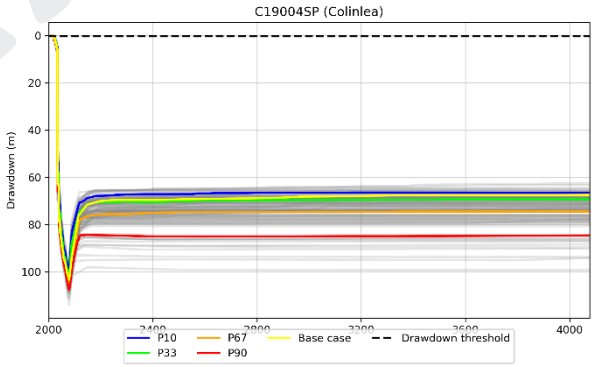

C18013SP (Clematis)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

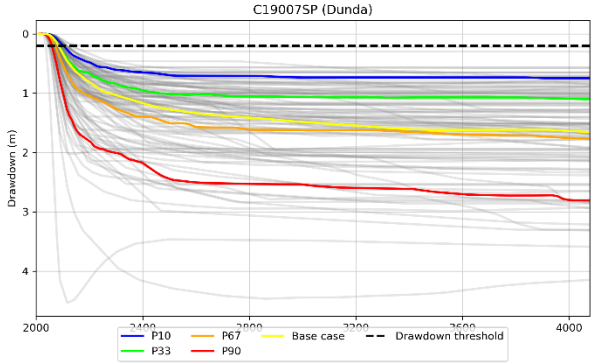

C18014SP (Clematis)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

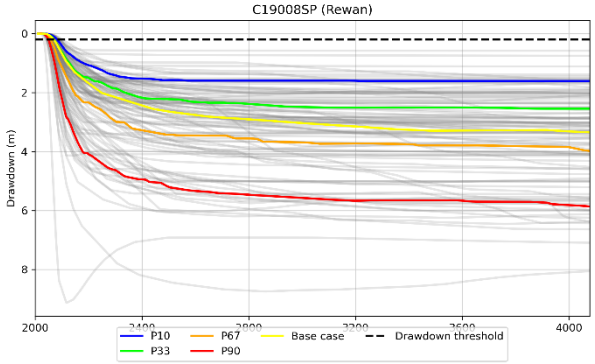

C19001SP (Alluvium)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

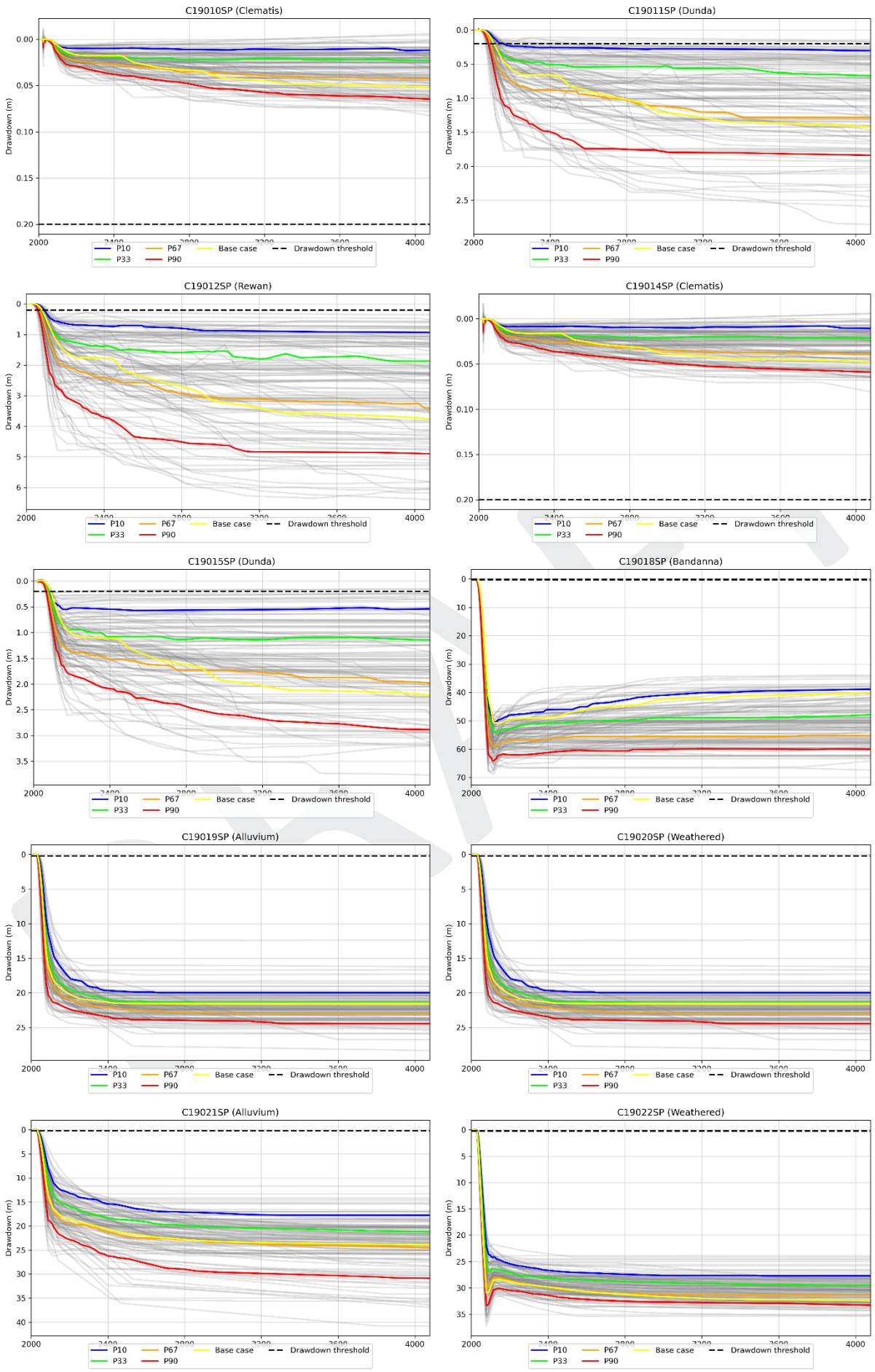

C19002SP (Clematis)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

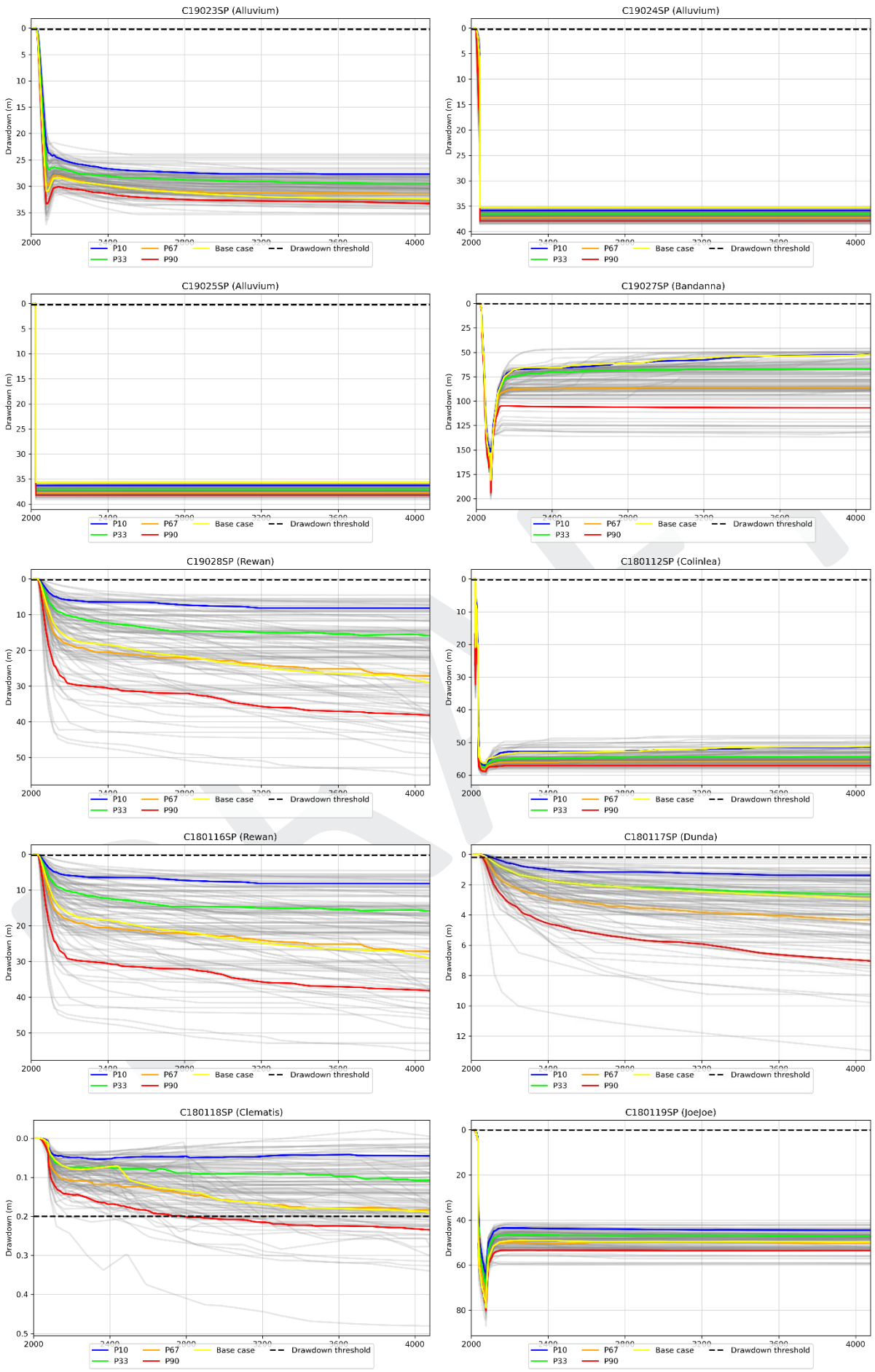

C19003SP (Colinlea)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

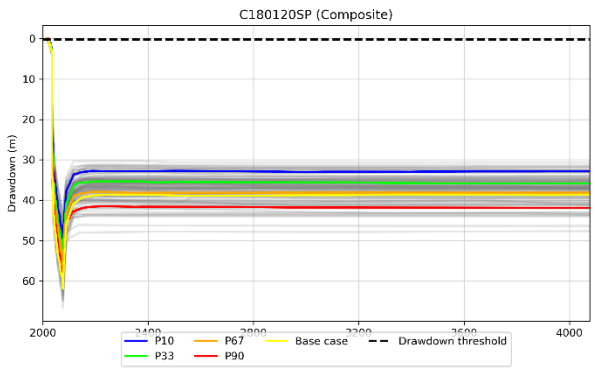

C19004SP (Colinlea)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

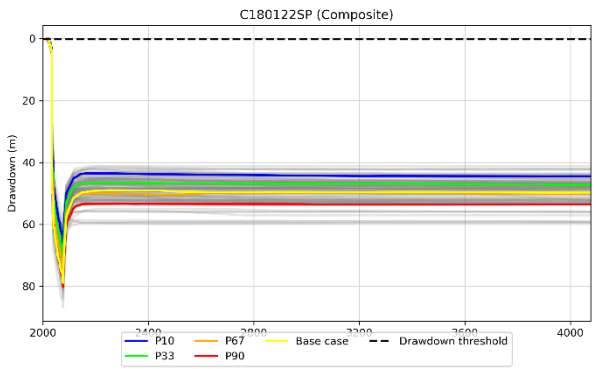

C19007SP (Dunda)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

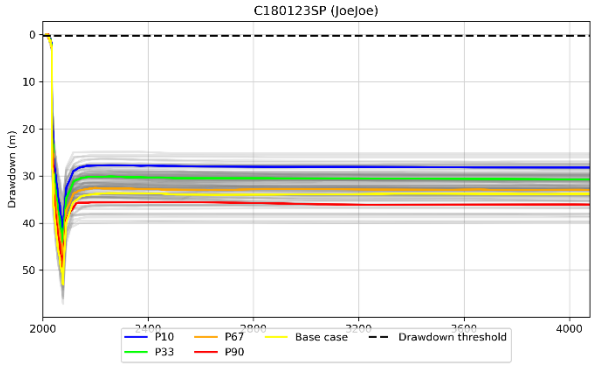

C19008SP (Rewan)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

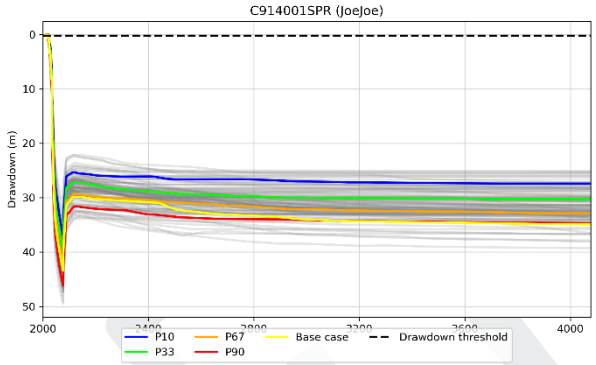

C19010SP (Clematis)
C19011SP (Dunda)
C19012SP (Rewan)
C19014SP (Clematis)
C19015SP (Dunda)
C19018SP (Bandanna)
C19019SP (Alluvium)
C19020SP (Weathered)
C19021SP (Alluvium)
C19022SP (Weathered)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

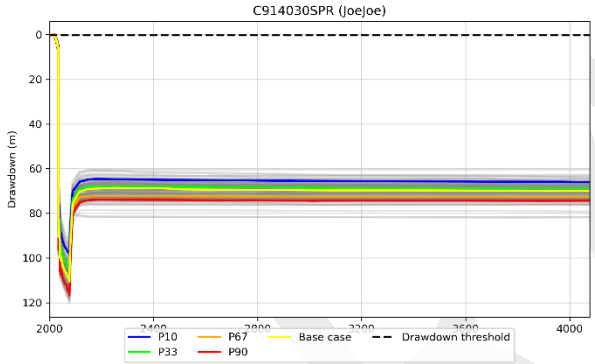

C19023SP (Alluvium)
C19024SP (Alluvium)
C19025SP (Alluvium)
C19027SP (Bandanna)
C19028SP (Rewan)
C180112SP (Colinlea)
C180116SP (Rewan)
C180117SP (Dunda)
C180118SP (Clematis)
C180119SP (JoeJoe)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

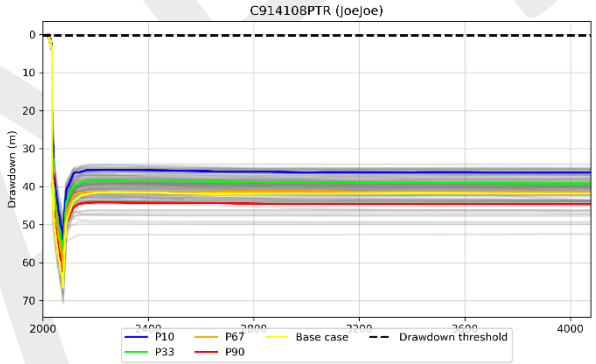

C180120SP (Composite)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

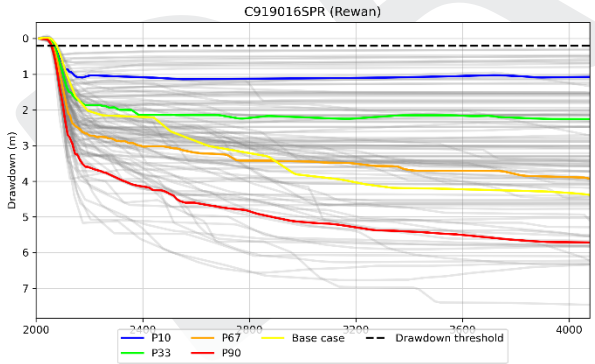

C180122SP (Composite)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

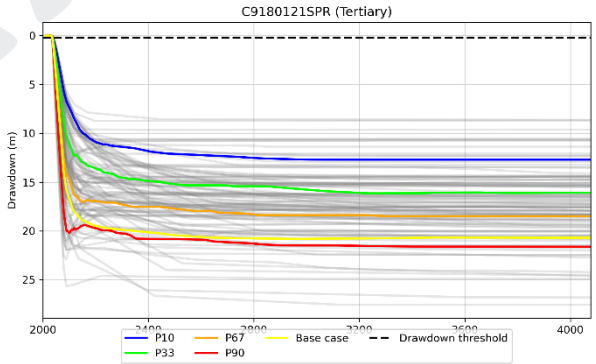

C180123SP (JoeJoe)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

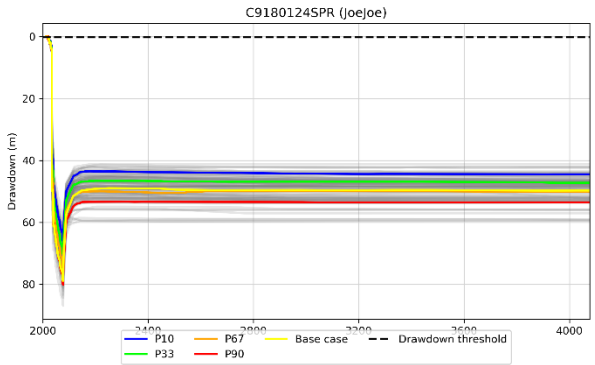

C914001SPR (JoeJoe)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

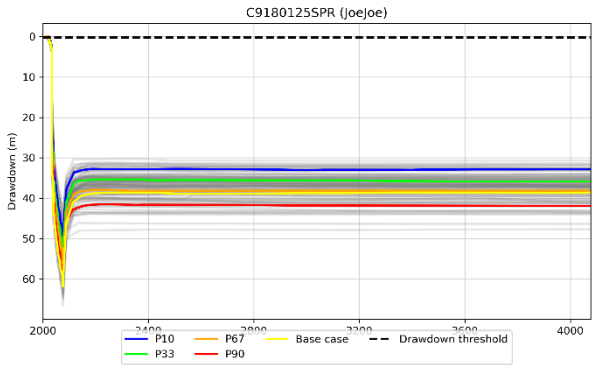

C914030SPR (JoeJoe)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

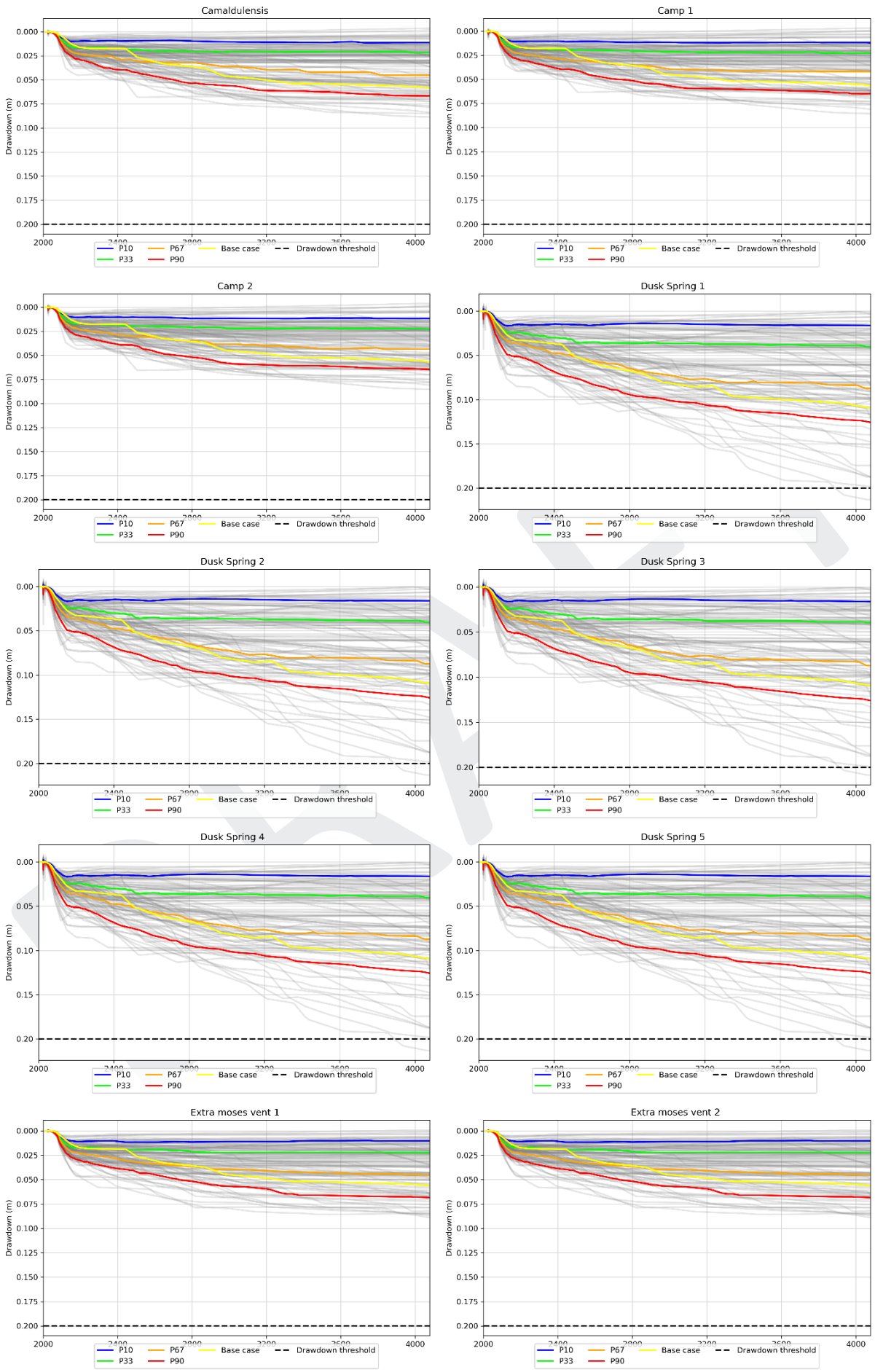

C914108PTR (JoeJoe)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

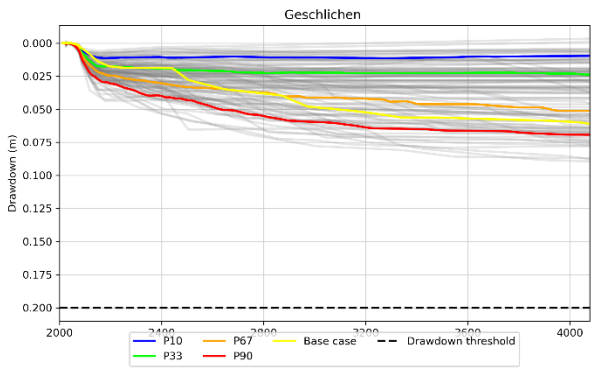

C919016SPR (Rewan)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

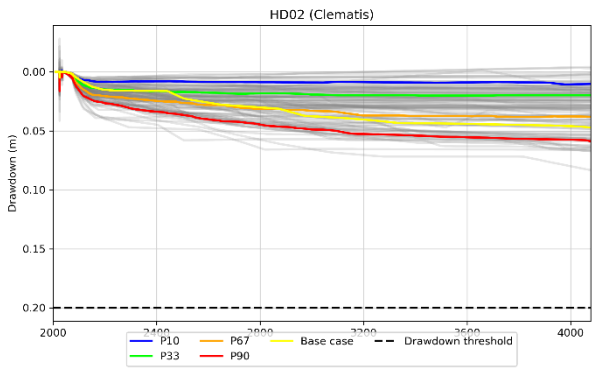

C9180121SPR (Tertiary)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

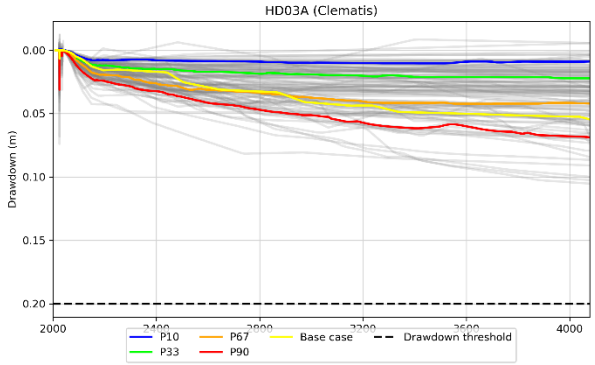

C9180124SPR (JoeJoe)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

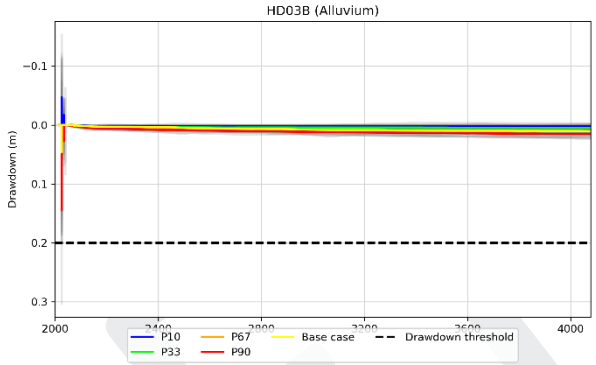

C9180125SPR (JoeJoe)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

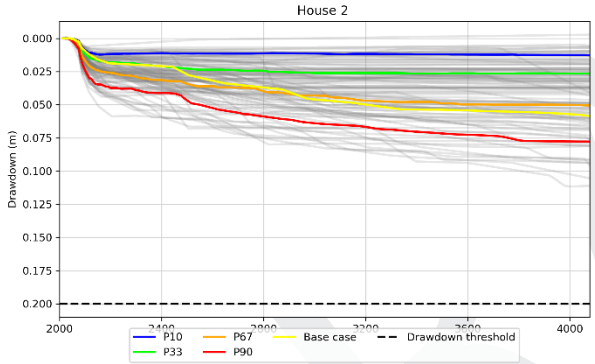

Camaldulensis
Camp 1
Camp 2
Dusk Spring 1
Dusk Spring 2
Dusk Spring 3
Dusk Spring 4
Dusk Spring 5
Extra moses vent 1
Extra moses vent 2
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

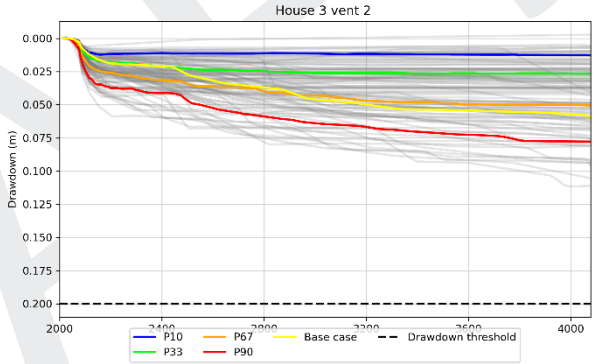

Geschlichen
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

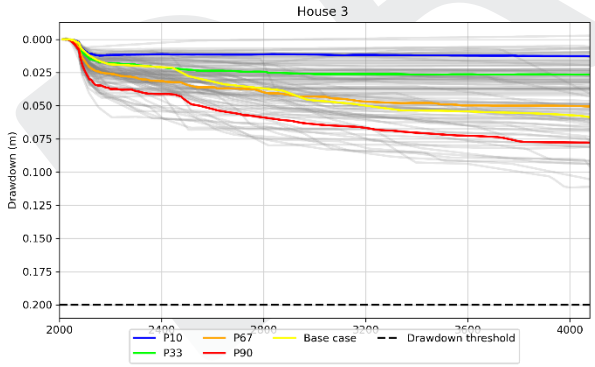

HD02 (Clematis)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

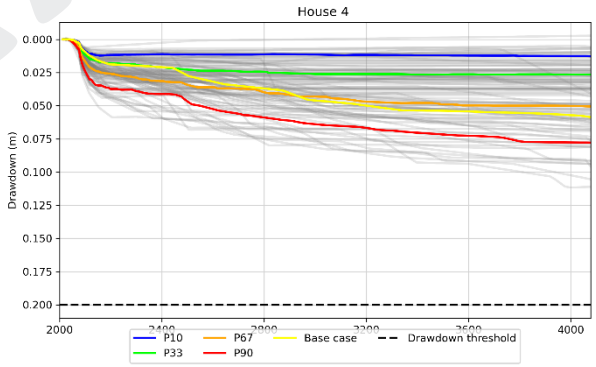

HD03A (Clematis)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

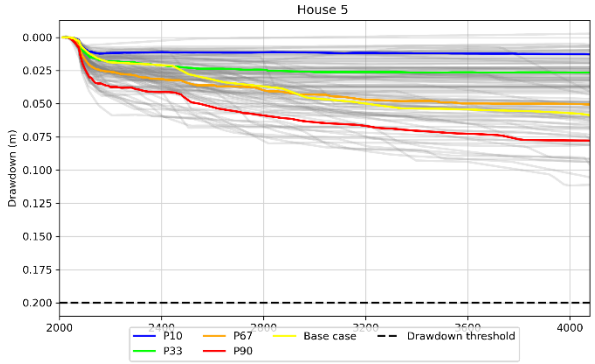

HD03B (Alluvium)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

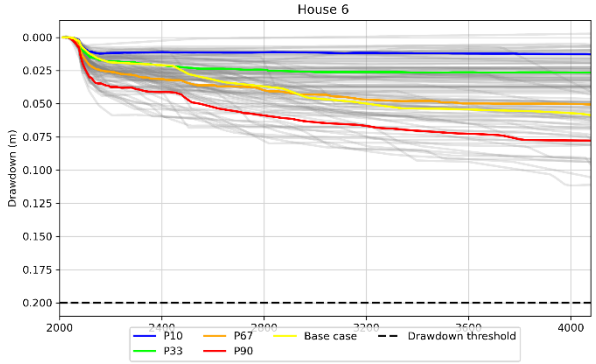

House 2
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

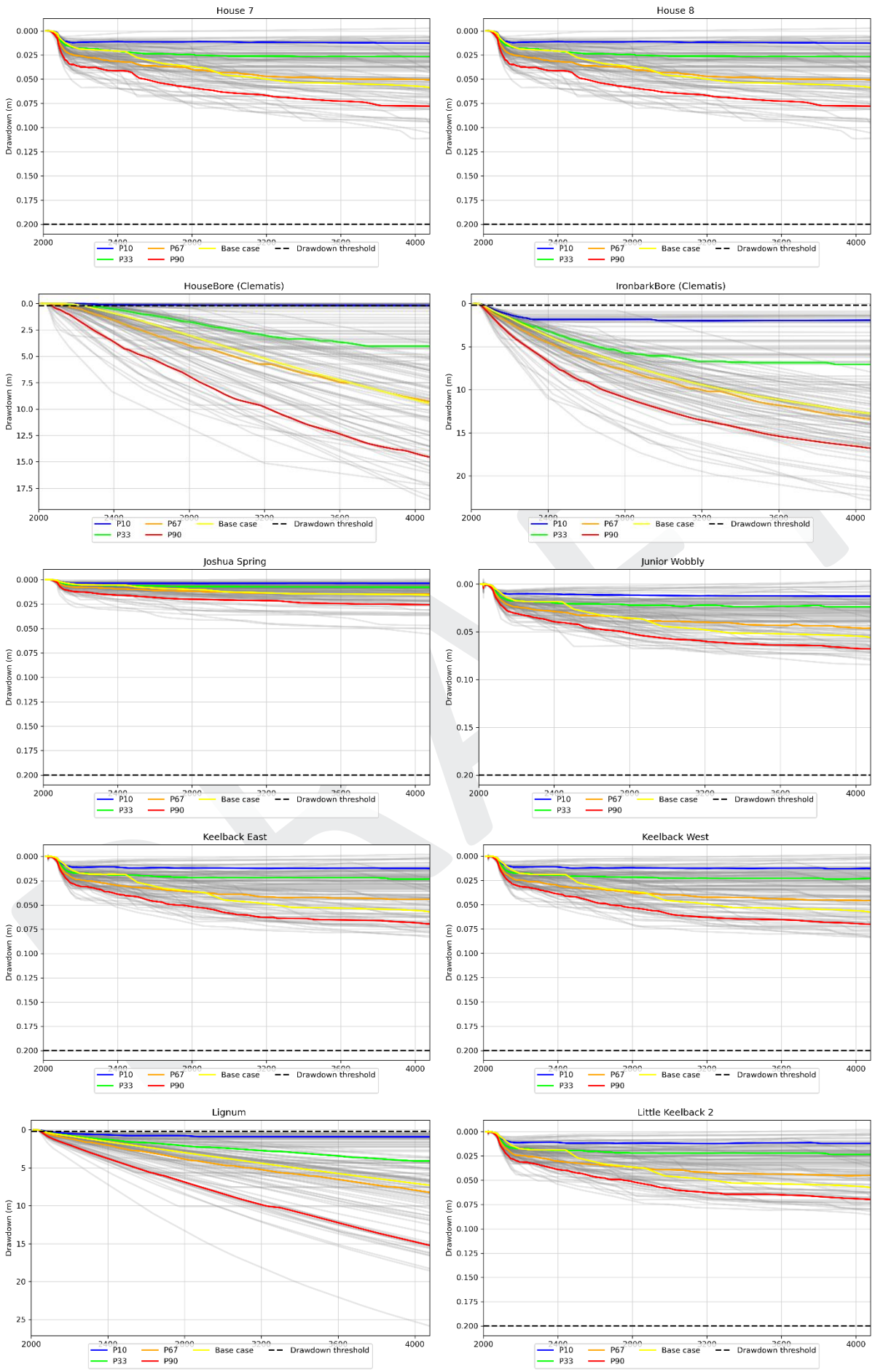

House 3 vent 2
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

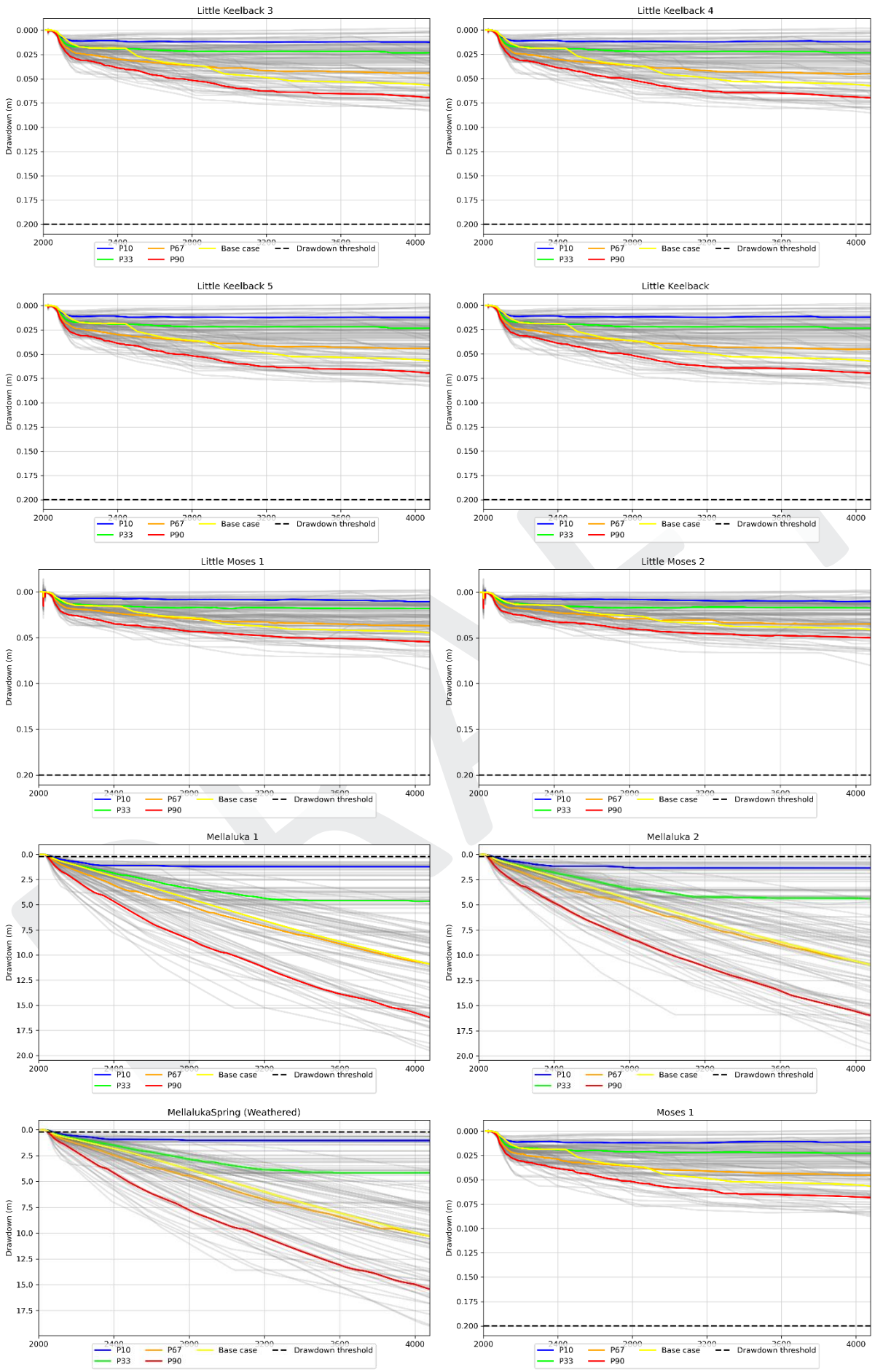

House 3
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

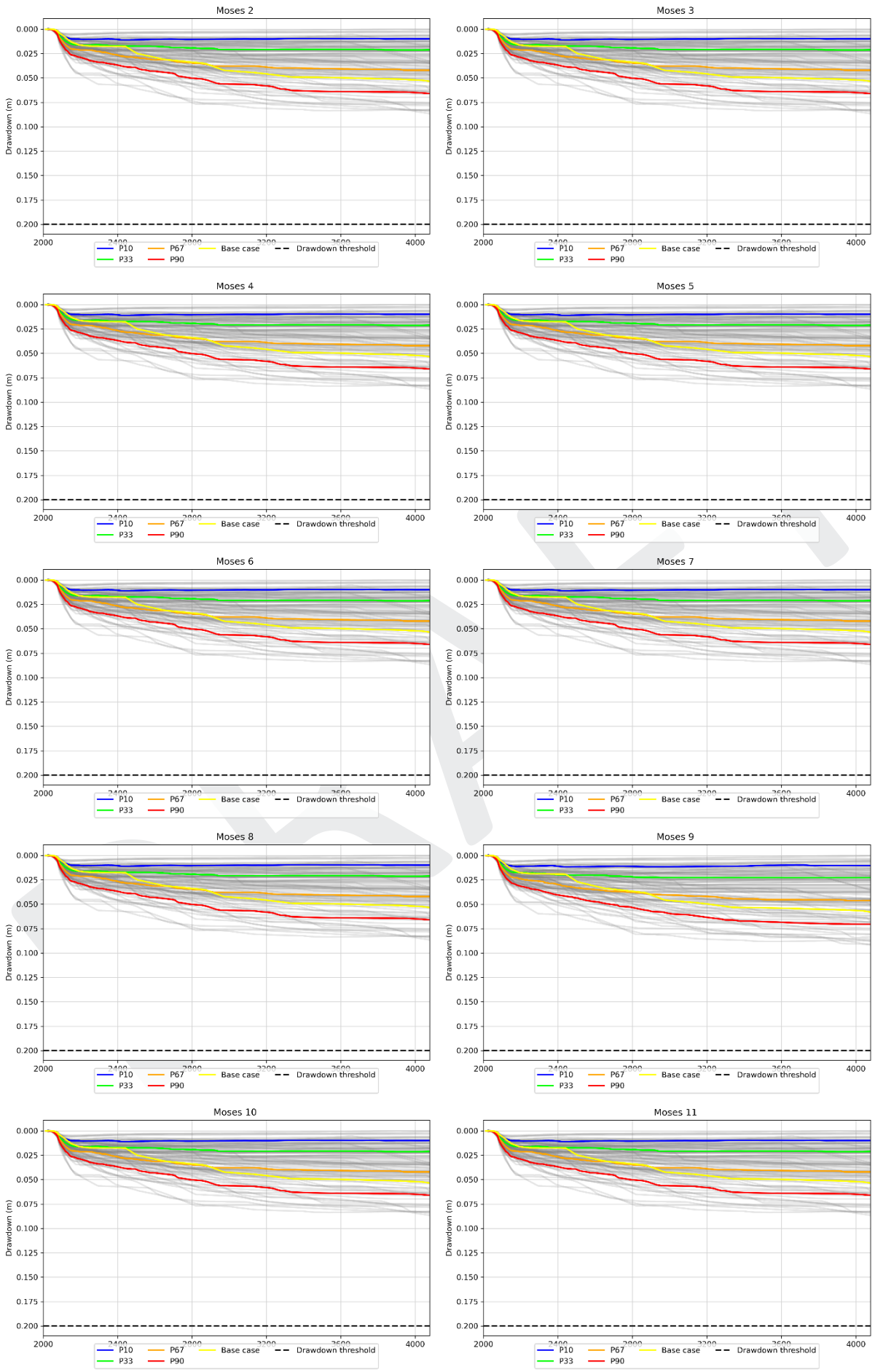

House 4
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

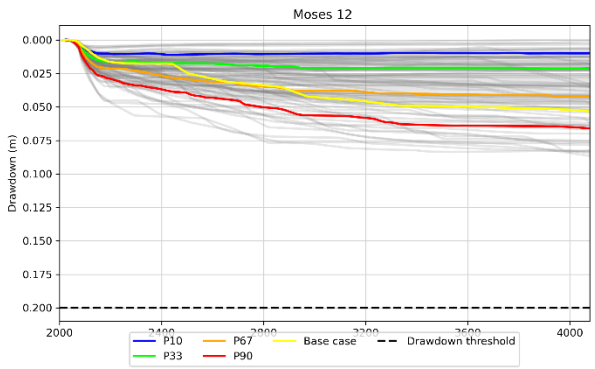

House 5
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

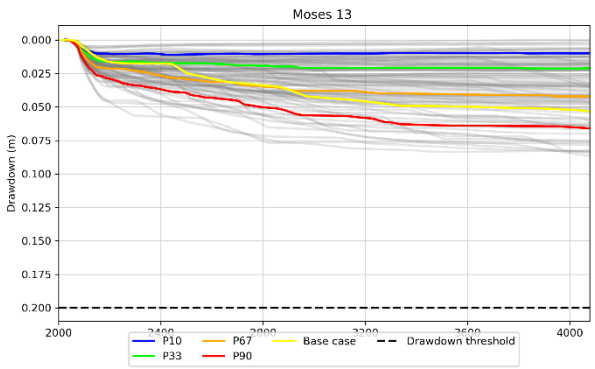

House 6
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

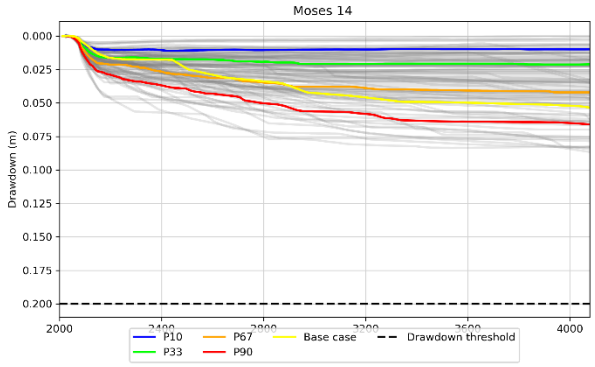

House 7
House 8
HouseBore (Clematis)
IronbarkBore (Clematis)
Joshua Spring
Junior Wobbly
Keelback East
Keelback West
Lignum
Little Keelback 2
Drawdown (m)
P10
P33
P67
P90
Base case
Drawdown threshold

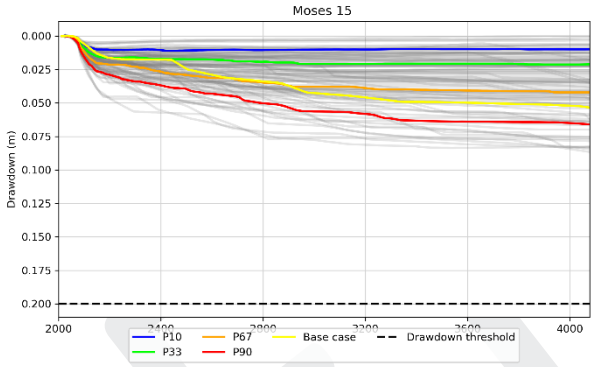

Little Keelback 3
Little Keelback 4
Little Keelback 5
Little Keelback
Little Moses 1
Little Moses 2
Mellaluka 1
Mellaluka 2
MellalukaSpring (Weathered)
Moses 1
Drawdown (m)
P10
P33
P67
P90
Base case
Drawdown threshold

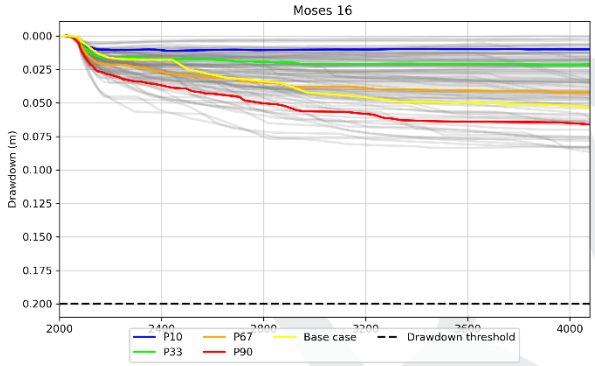

Moses 2
Moses 3
Moses 4
Moses 5
Moses 6
Moses 7
Moses 8
Moses 9
Moses 10
Moses 11
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

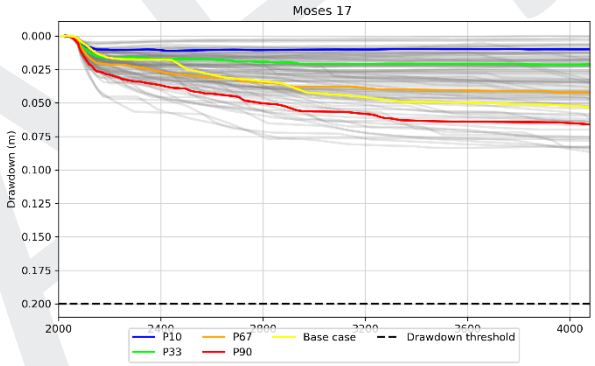

Moses 12
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

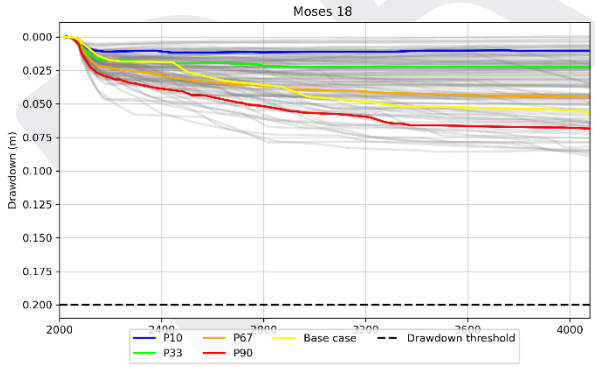

Moses 13
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

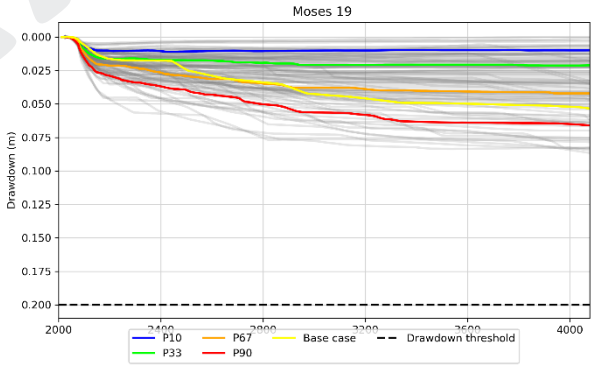

Moses 14
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

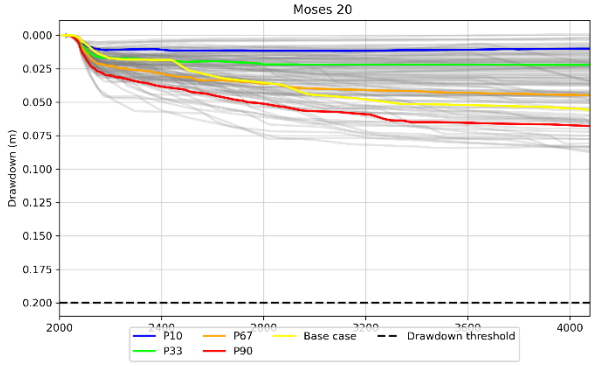

Moses 15
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

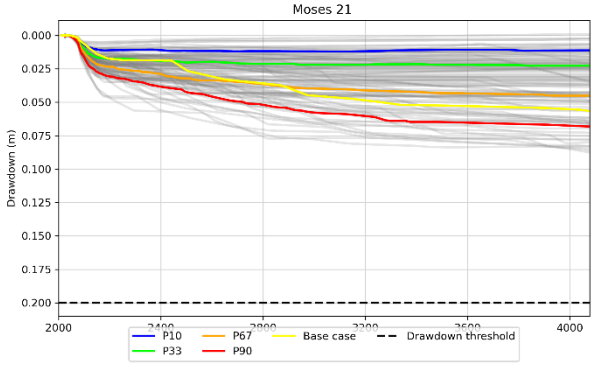

Moses 16
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

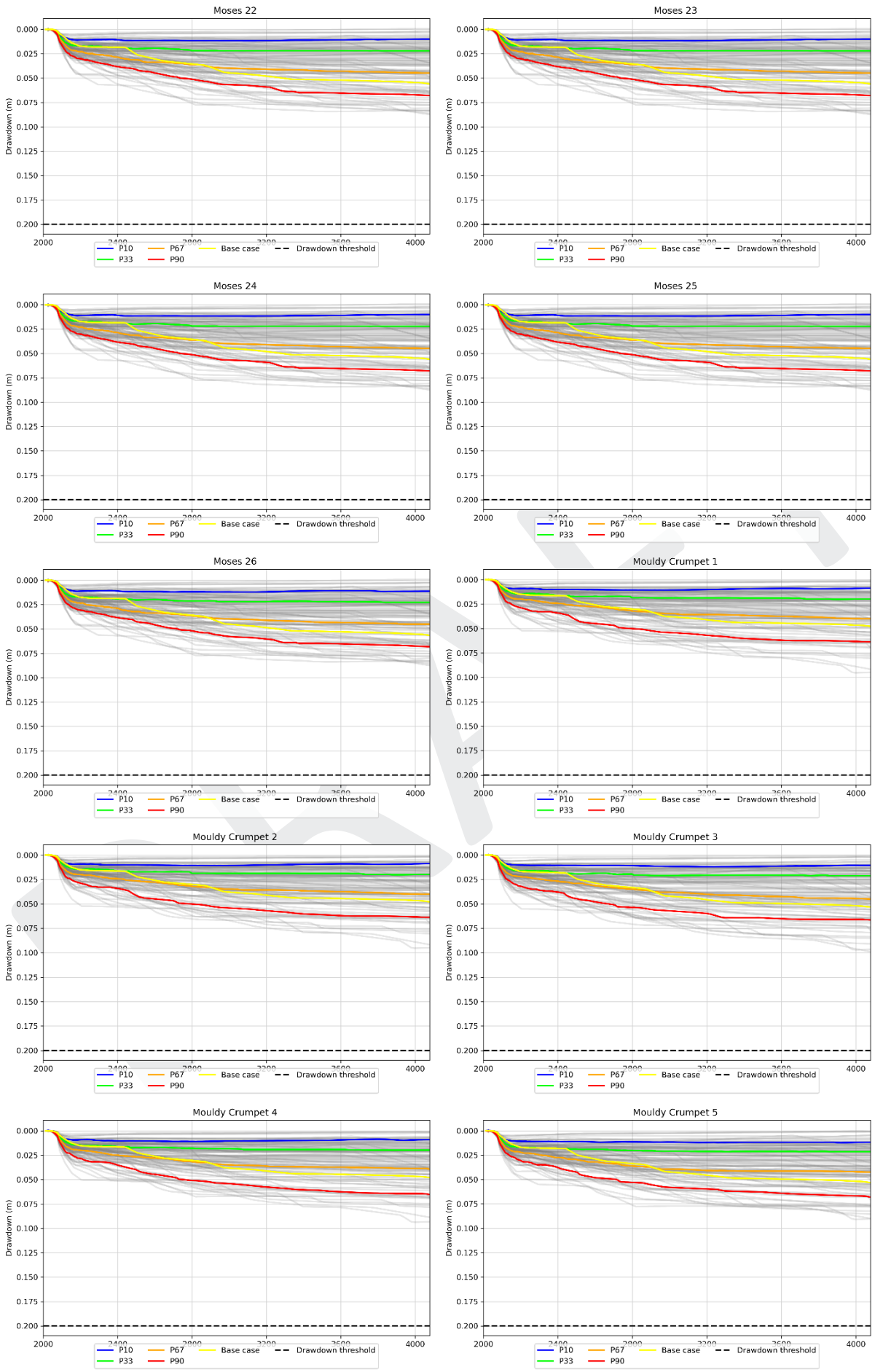

Moses 17
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

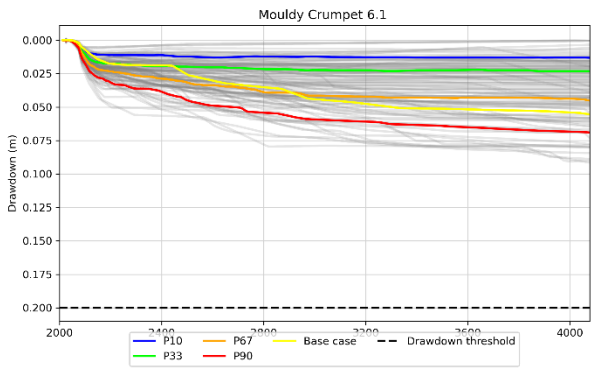

Moses 18
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

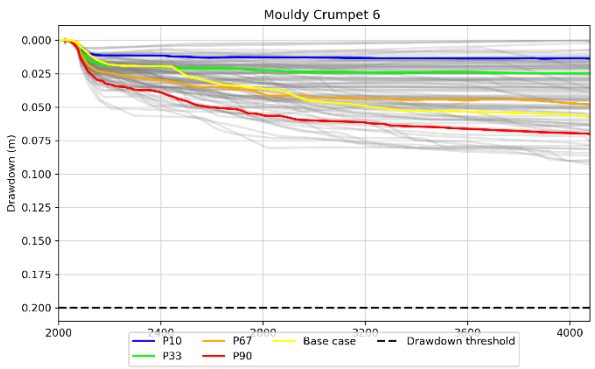

Moses 19
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

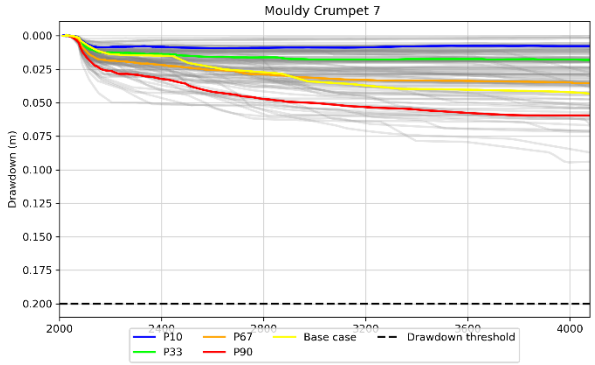

Moses 20
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

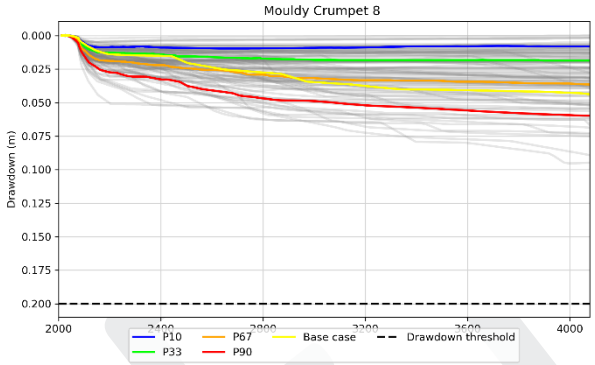

Moses 21
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

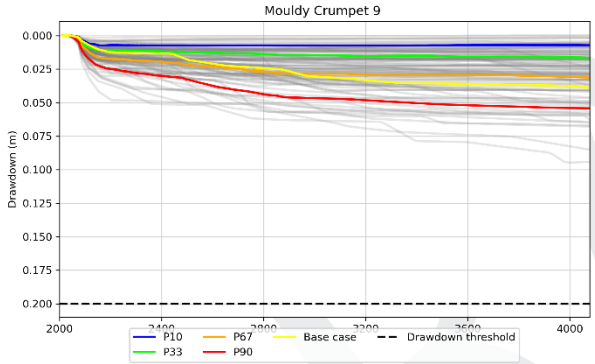

Moses 22
Moses 23
Moses 24
Moses 25
Moses 26
Mouldy Crumpet 1
Mouldy Crumpet 2
Mouldy Crumpet 3
Mouldy Crumpet 4
Mouldy Crumpet 5
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
4000
P10
P67
Base case
Drawdown threshold
P33
P90

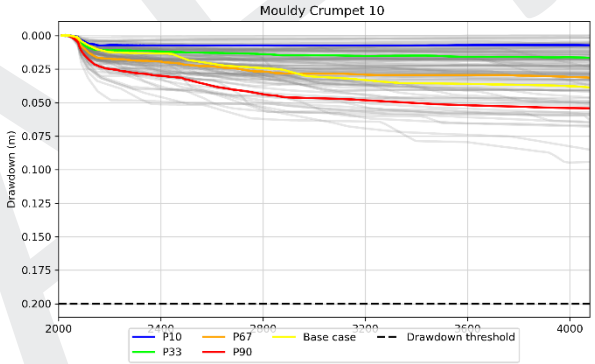

Mouldy Crumpet 6.1
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
4000
P10
P67
Base case
Drawdown threshold
P33
P90

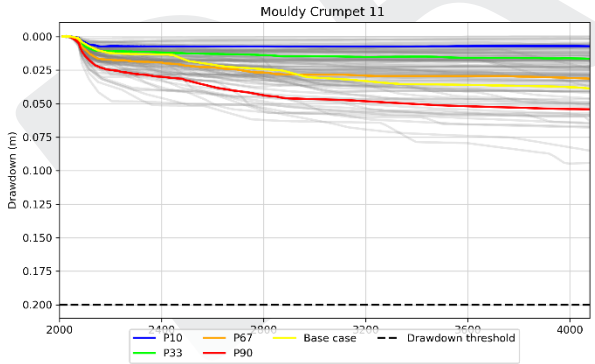

Mouldy Crumpet 6
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
4000
P10
P67
Base case
Drawdown threshold
P33
P90

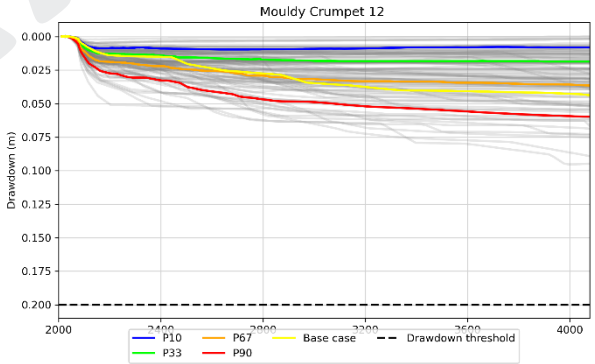

Mouldy Crumpet 7
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
4000
P10
P67
Base case
Drawdown threshold
P33
P90

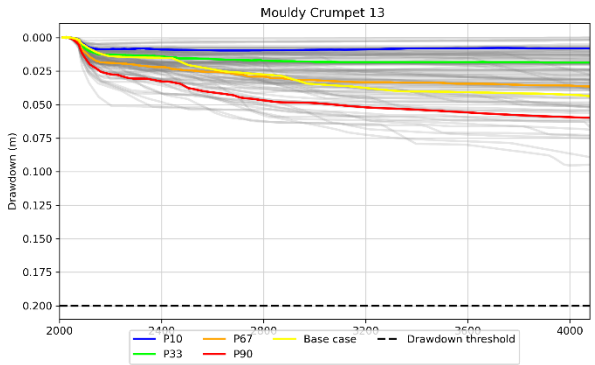

Mouldy Crumpet 8
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
4000
P10
P67
Base case
Drawdown threshold
P33
P90

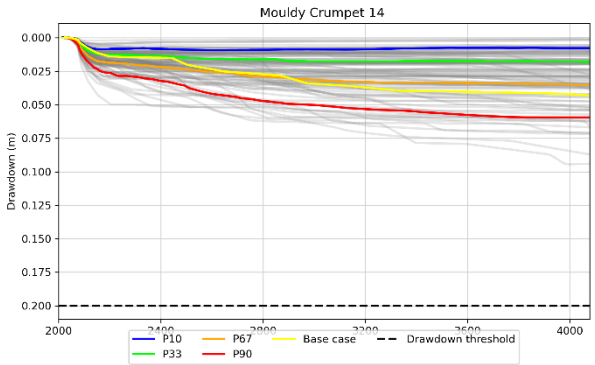

Mouldy Crumpet 9
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
4000
P10
P67
Base case
Drawdown threshold
P33
P90

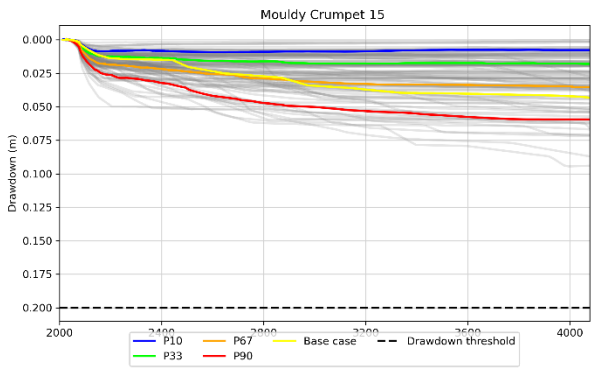

Mouldy Crumpet 10
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
4000
P10
P67
Base case
Drawdown threshold
P33
P90

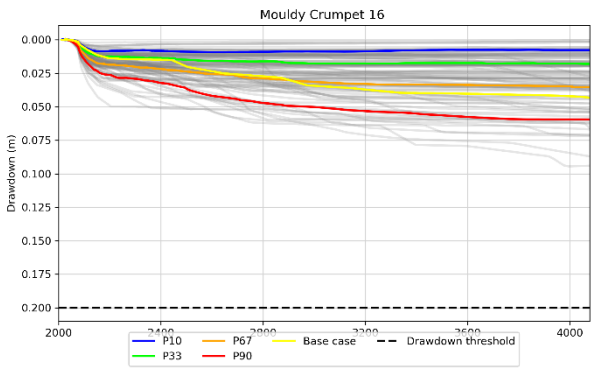

Mouldy Crumpet 11
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
4000
P10
P67
Base case
Drawdown threshold
P33
P90

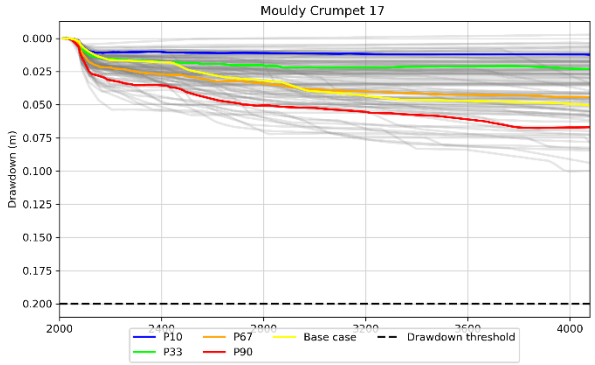

Mouldy Crumpet 12
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
4000
P10
P67
Base case
Drawdown threshold
P33
P90

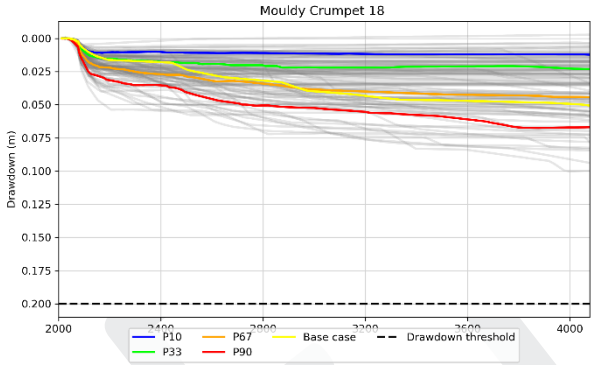

Mouldy Crumpet 13
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
4000
P10
P67
Base case
Drawdown threshold
P33
P90

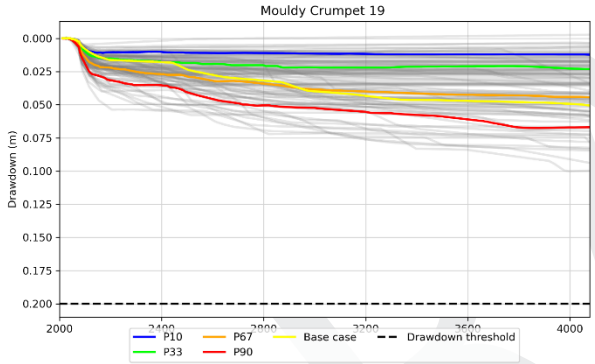

Mouldy Crumpet 14
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
4000
P10
P67
Base case
Drawdown threshold
P33
P90

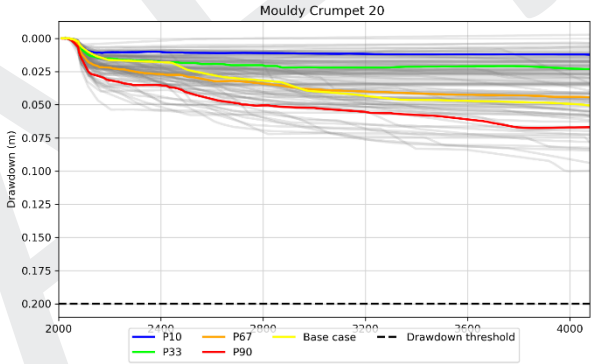

Mouldy Crumpet 15
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

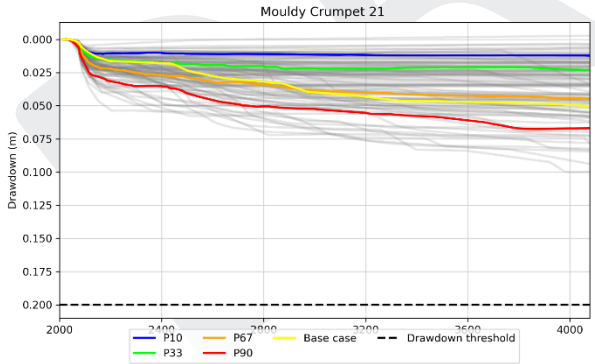

Mouldy Crumpet 16
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

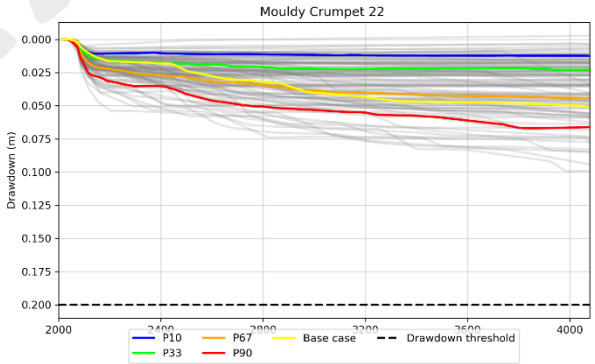

Mouldy Crumpet 17
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

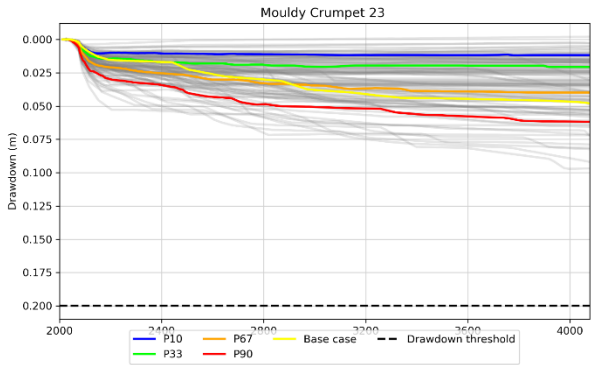

Mouldy Crumpet 18
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

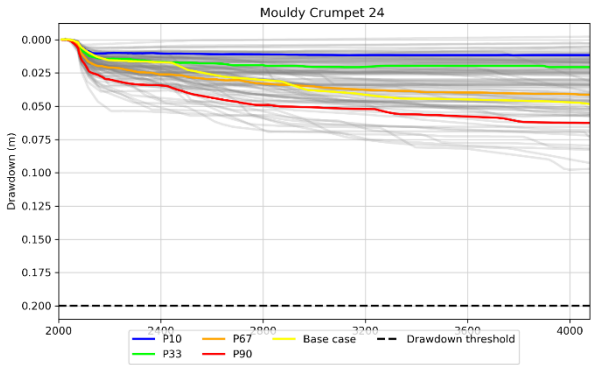

Mouldy Crumpet 19
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

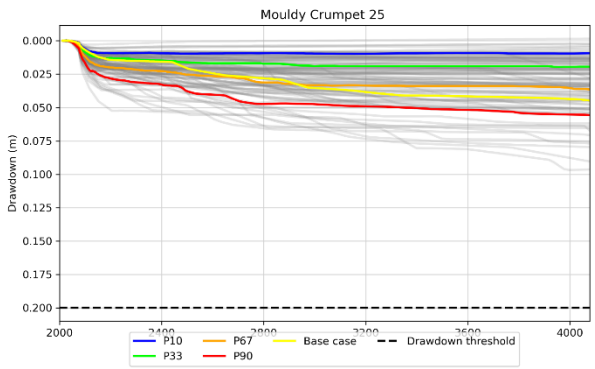

Mouldy Crumpet 20
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

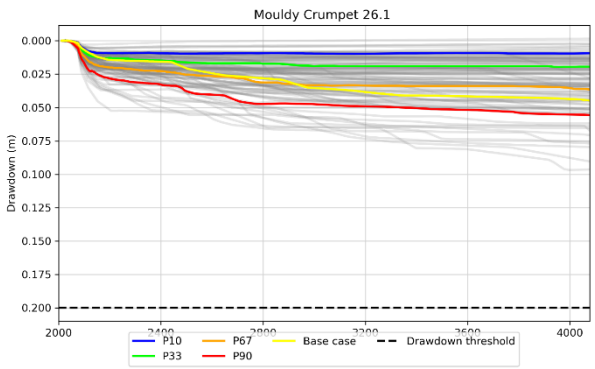

Mouldy Crumpet 21
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

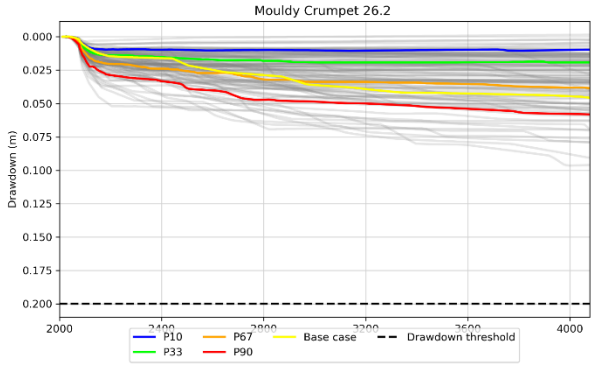

Mouldy Crumpet 22
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

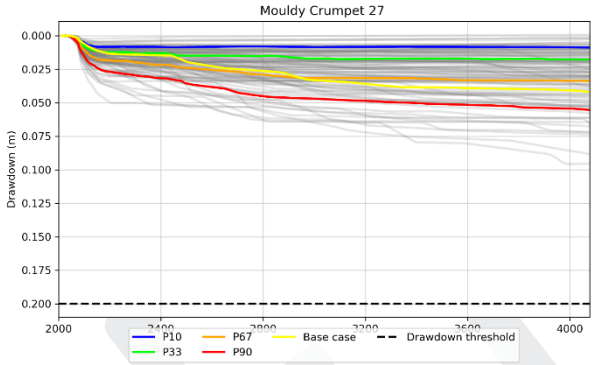

Mouldy Crumpet 23
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

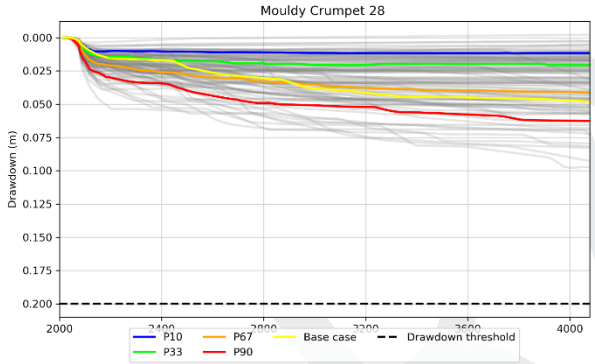

Mouldy Crumpet 24
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

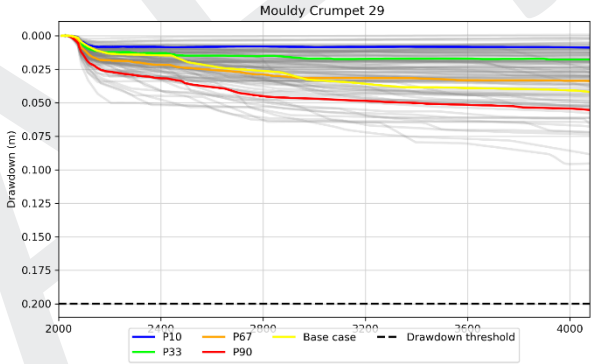

Mouldy Crumpet 25
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

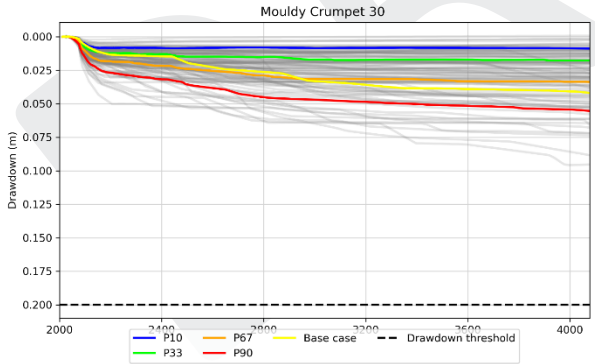

Mouldy Crumpet 26.1
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

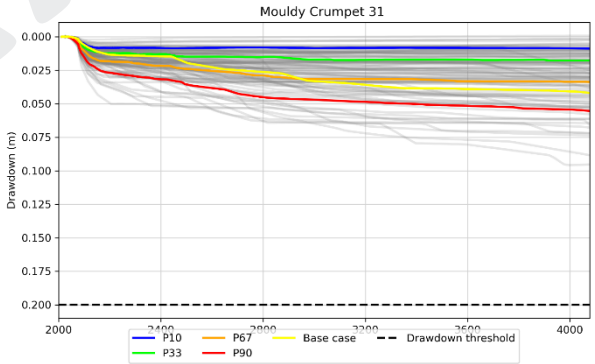

Mouldy Crumpet 26.2
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

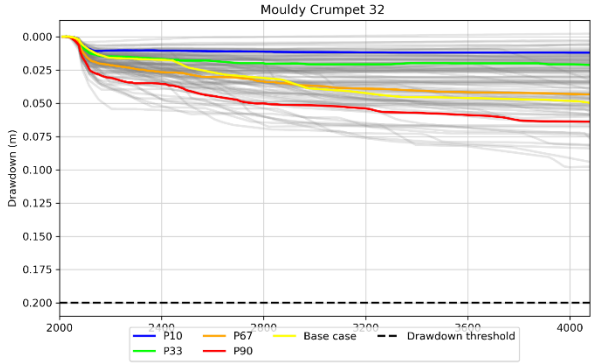

Mouldy Crumpet 27
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

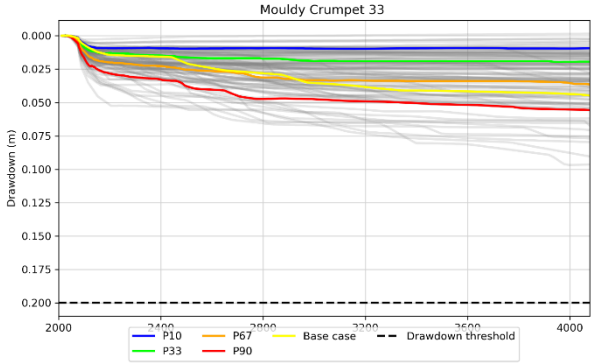

Mouldy Crumpet 28
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

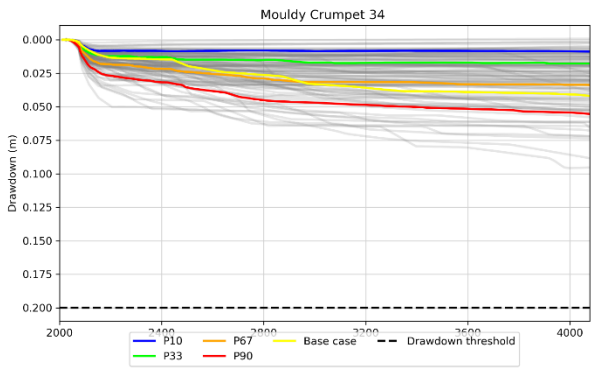

Mouldy Crumpet 29
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

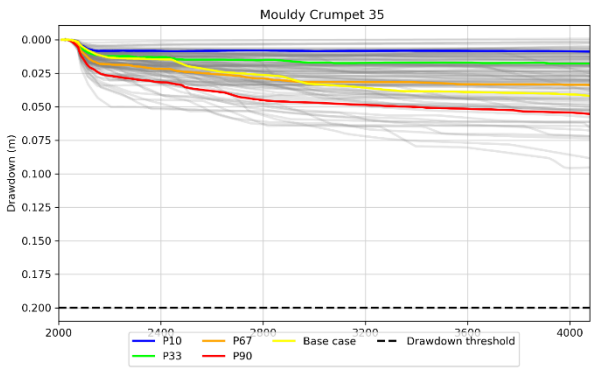

Mouldy Crumpet 30
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

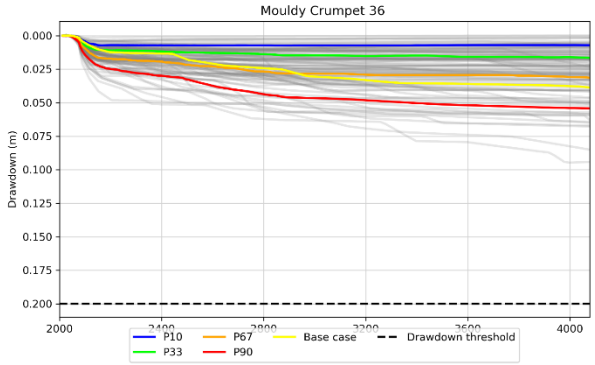

Mouldy Crumpet 31
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

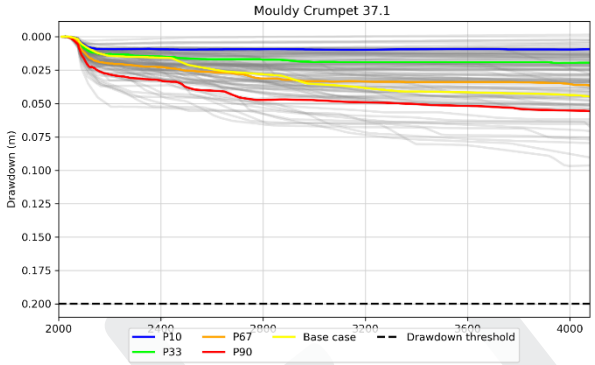

Mouldy Crumpet 32
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

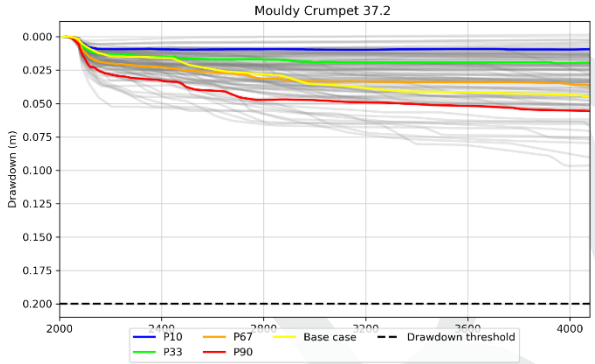

Mouldy Crumpet 33
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

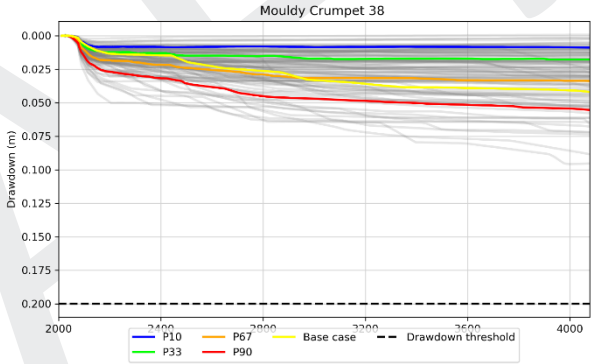

Mouldy Crumpet 34
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

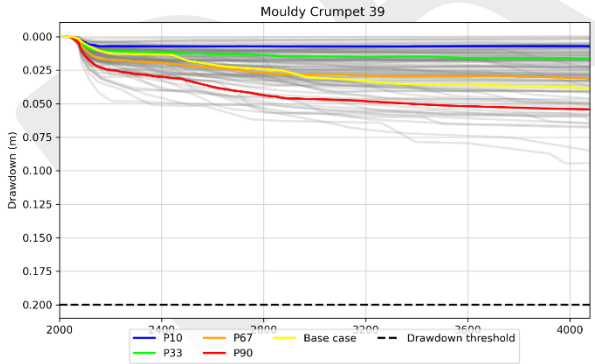

Mouldy Crumpet 35
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

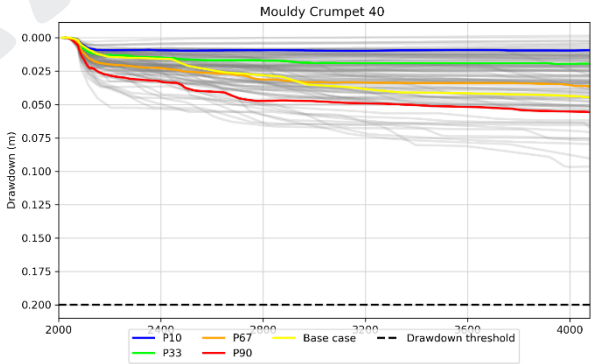

Mouldy Crumpet 36
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

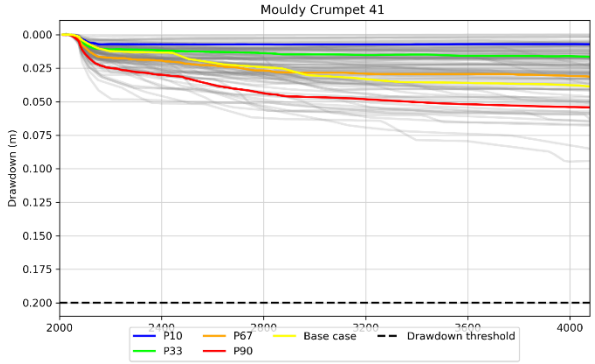

Mouldy Crumpet 37.1
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

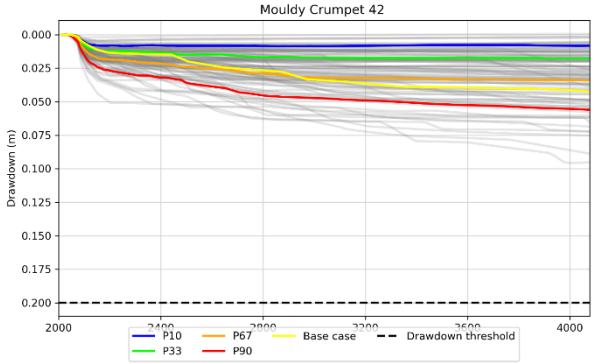

Mouldy Crumpet 37.2
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

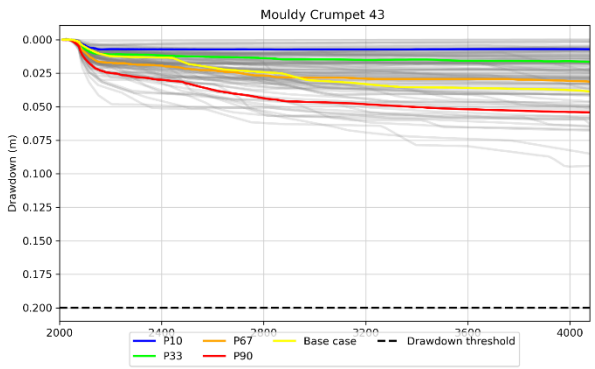

Mouldy Crumpet 38
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

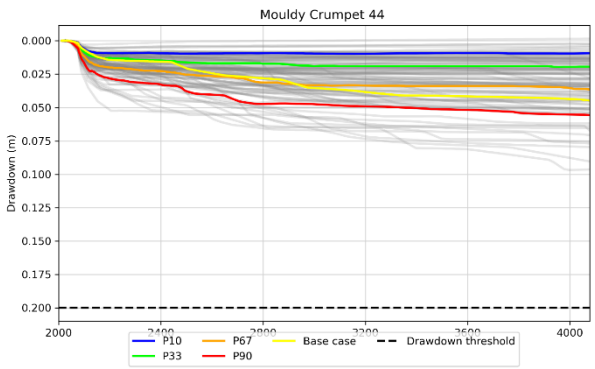

Mouldy Crumpet 39
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

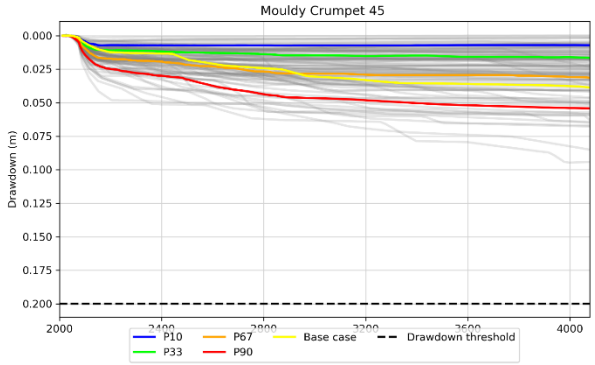

Mouldy Crumpet 40
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

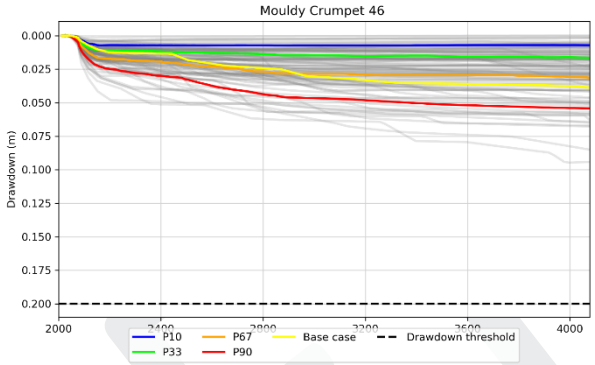

Mouldy Crumpet 41
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

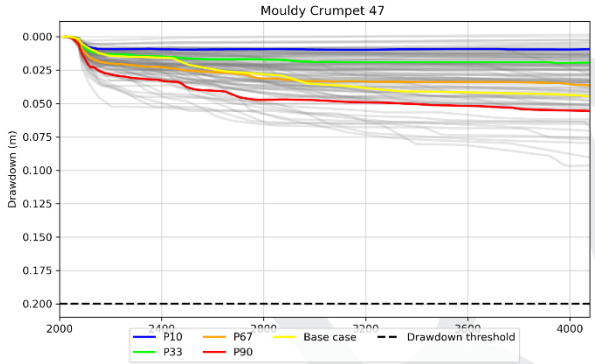

Mouldy Crumpet 42
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

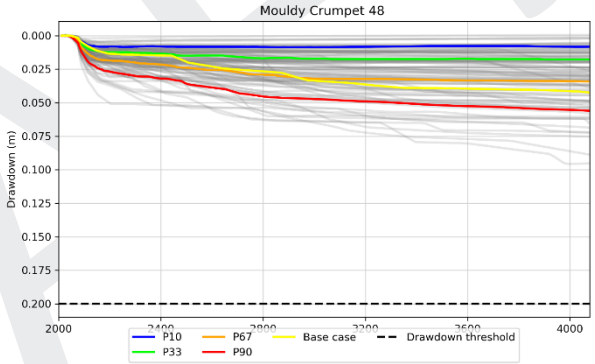

Mouldy Crumpet 43
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

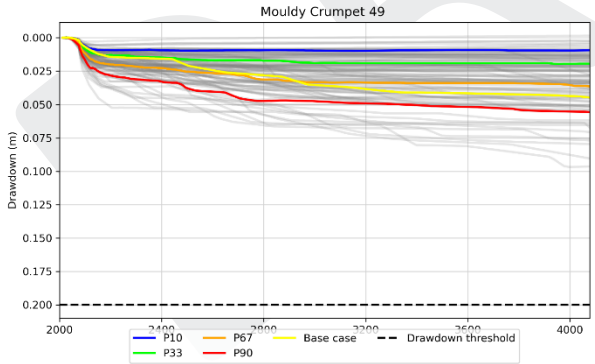

Mouldy Crumpet 44
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

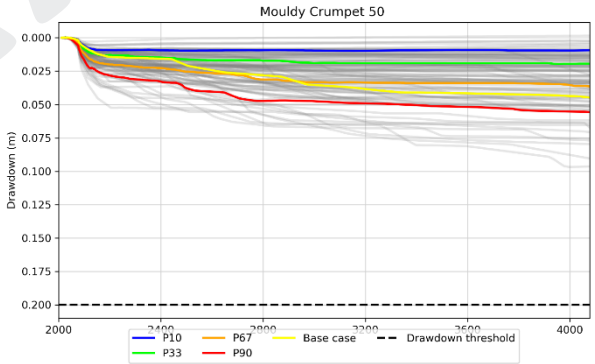

Mouldy Crumpet 45
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

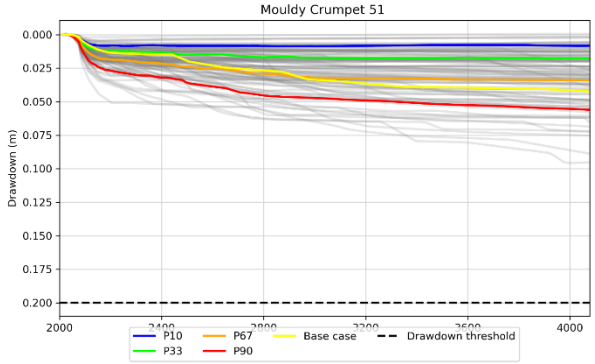

Mouldy Crumpet 46
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

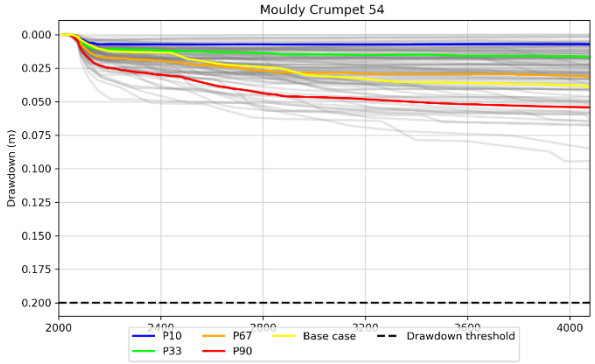

Mouldy Crumpet 47
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

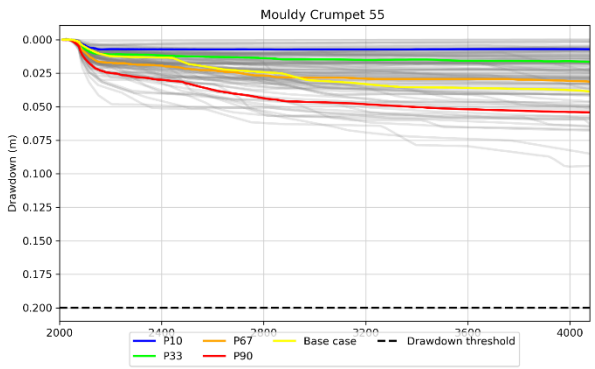

Mouldy Crumpet 48
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

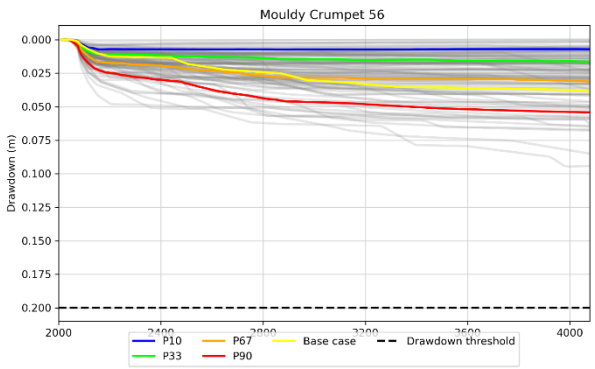

Mouldy Crumpet 49
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

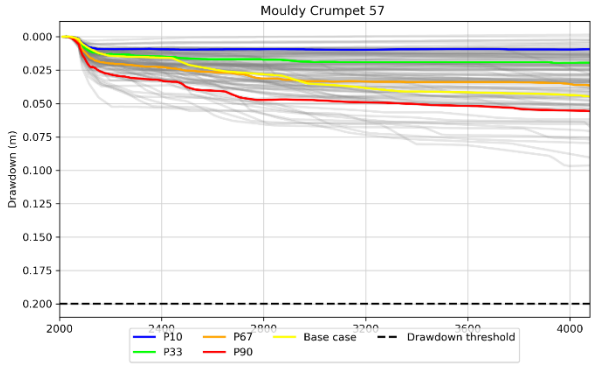

Mouldy Crumpet 50
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

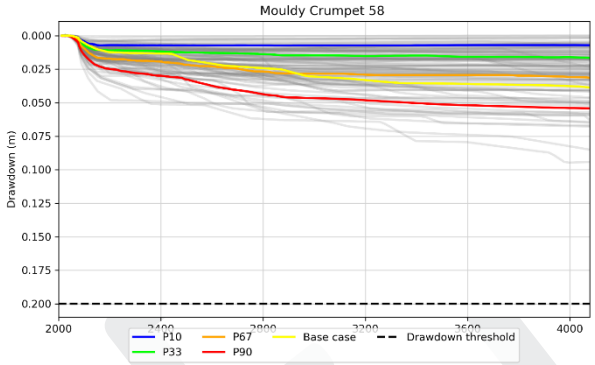

Mouldy Crumpet 51
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

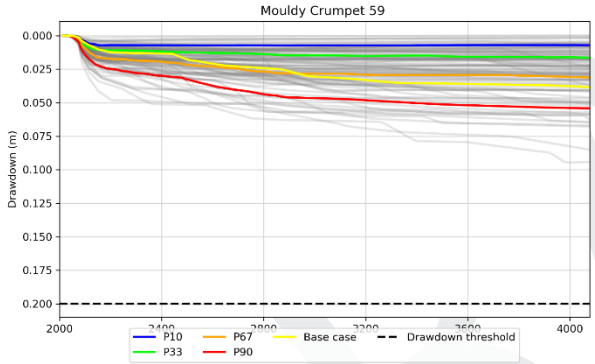

Mouldy Crumpet 54
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

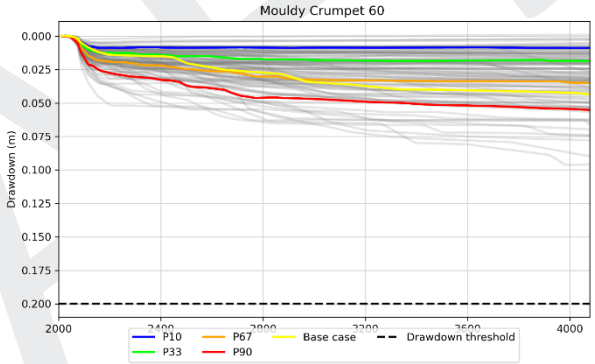

Mouldy Crumpet 55
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 56
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 57
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 58
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 59
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 60
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
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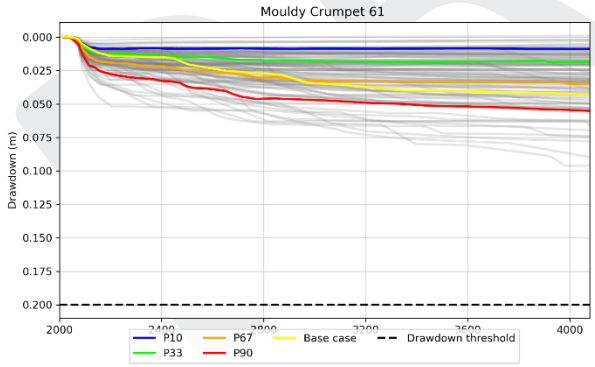
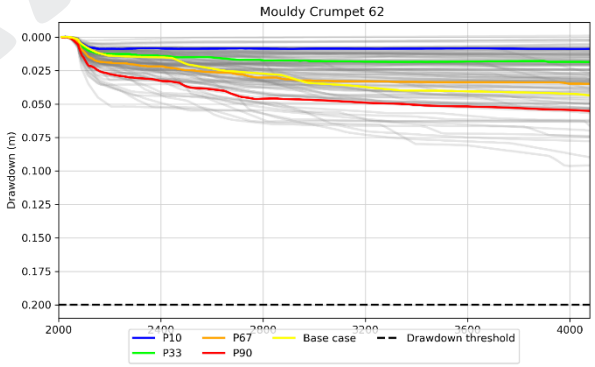
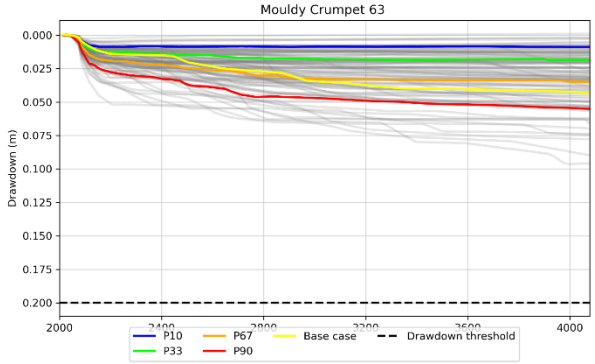
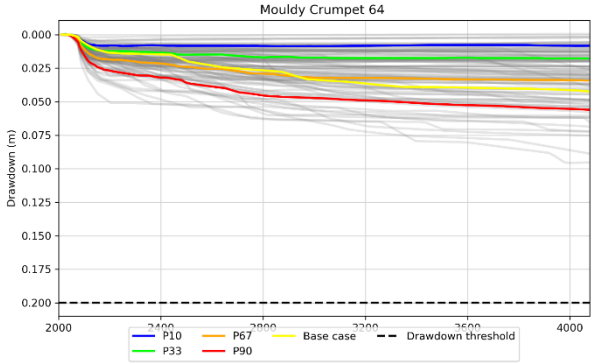
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 61
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 62
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 63
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 64
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
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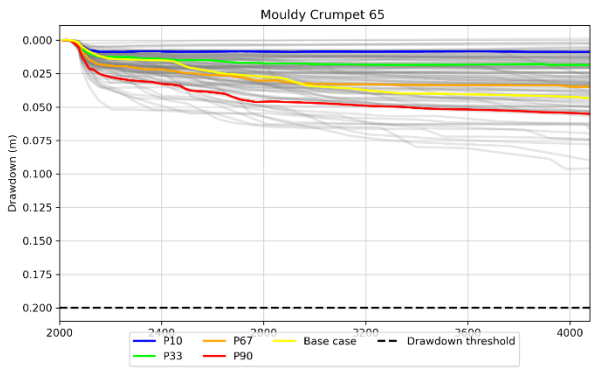
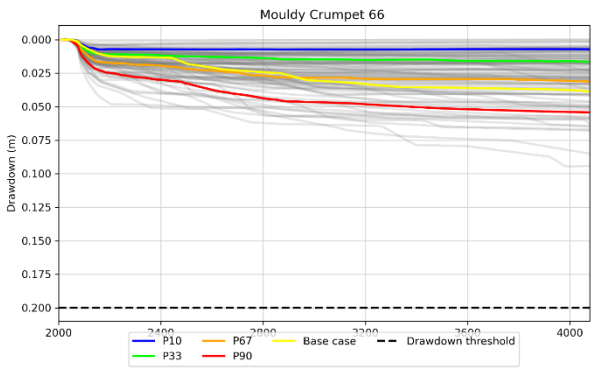
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 65
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 66
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
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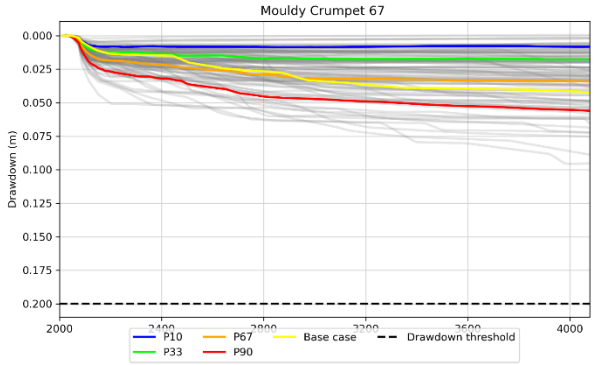
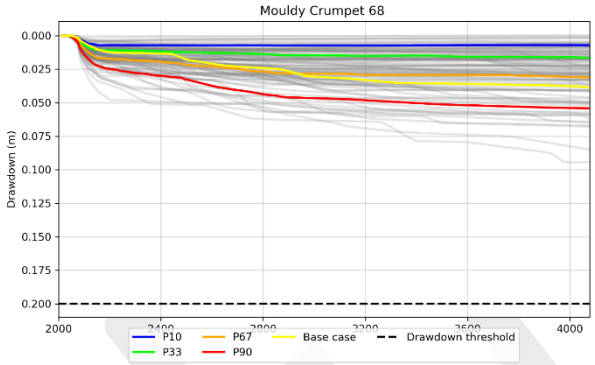
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 67
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 68
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
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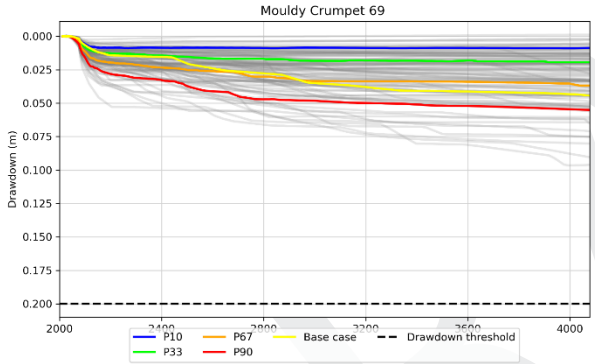
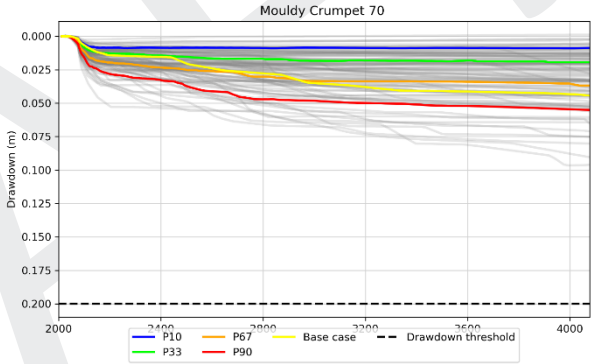
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 69
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 70
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
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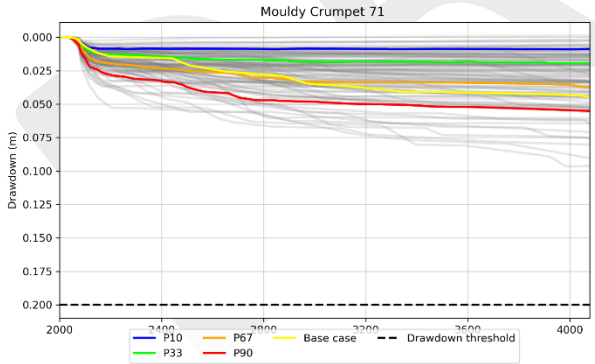
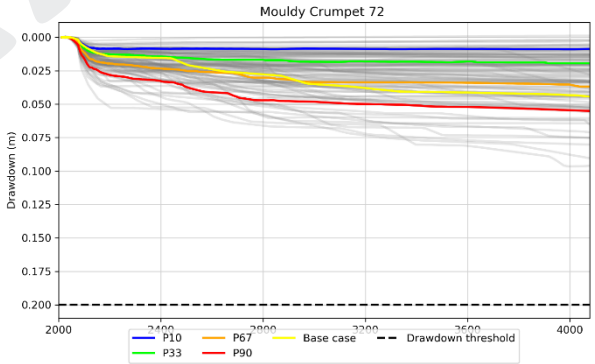
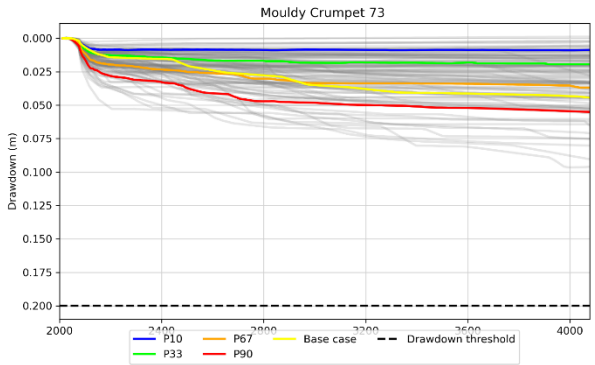
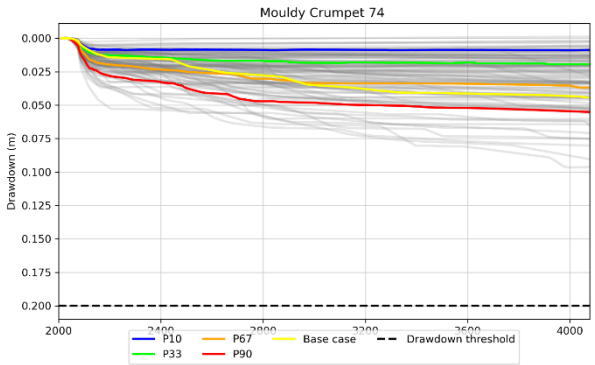
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 71
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 72
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 73
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 74
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
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0.175
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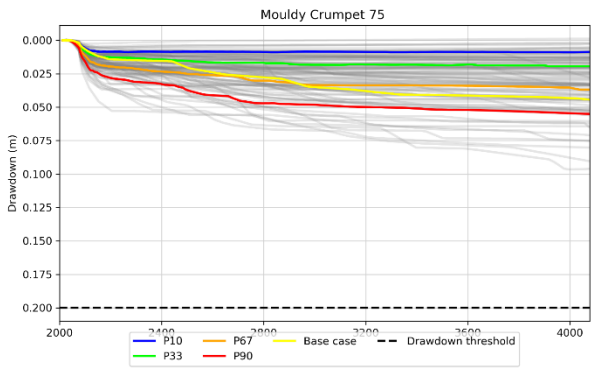
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 75
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
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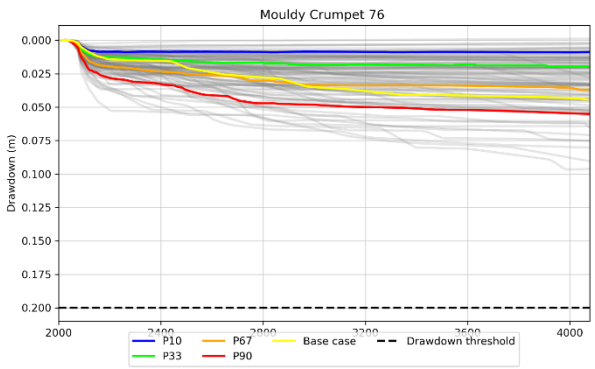
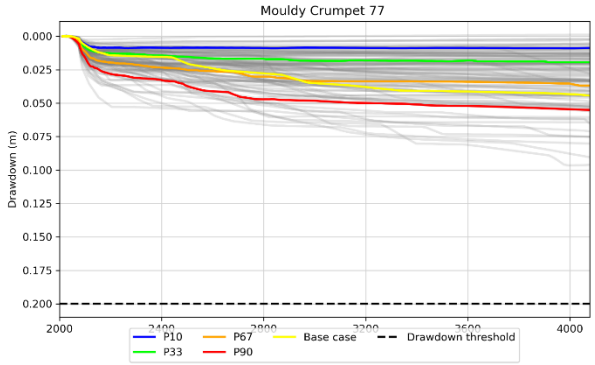
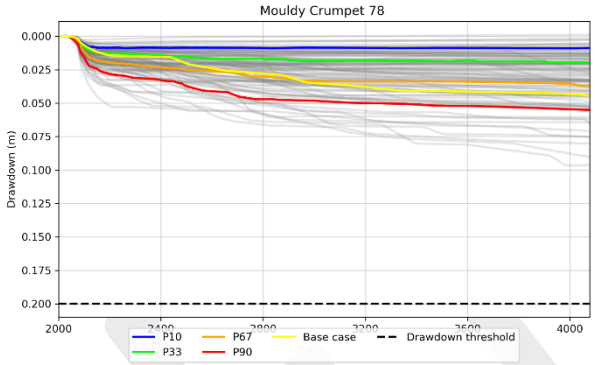
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 76
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 77
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 78
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
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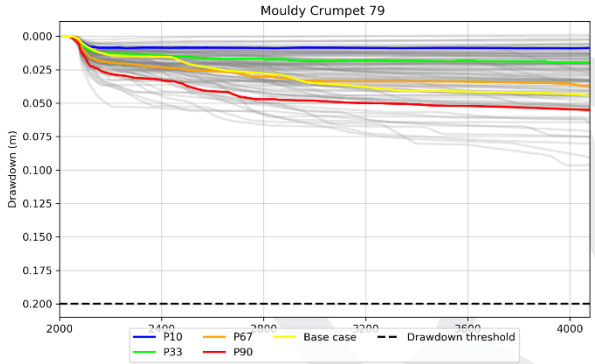
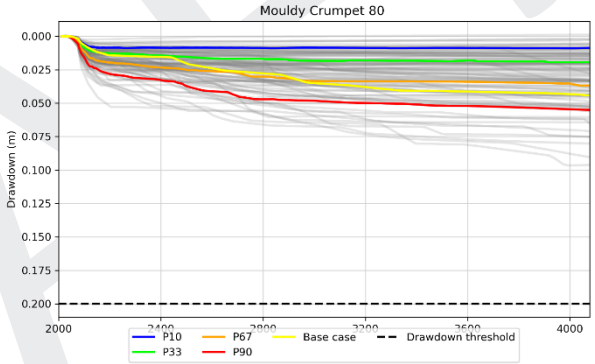
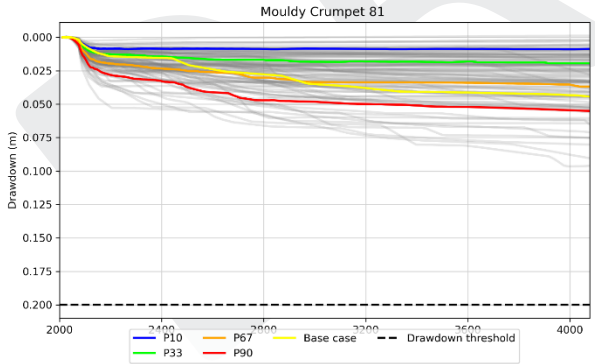
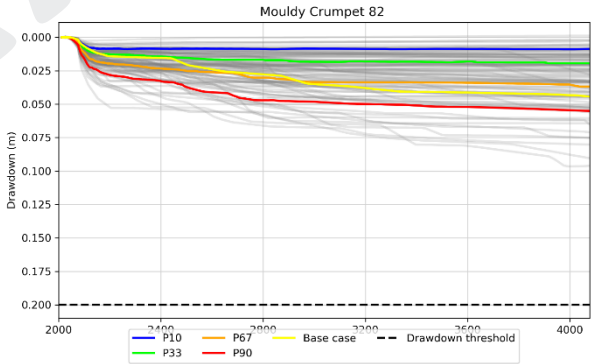
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 79
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 80
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 81
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 82
Drawdown (m)
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0.050
0.075
0.100
0.125
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2000
2400
2800
3200
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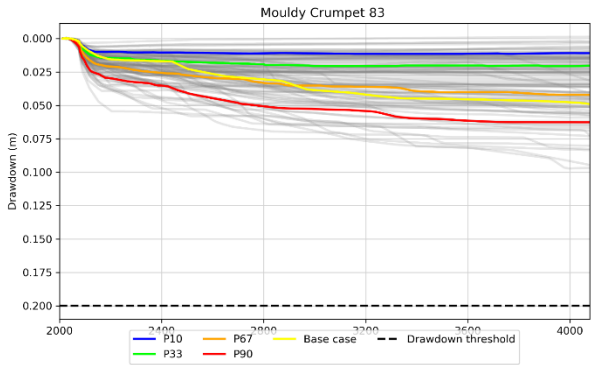
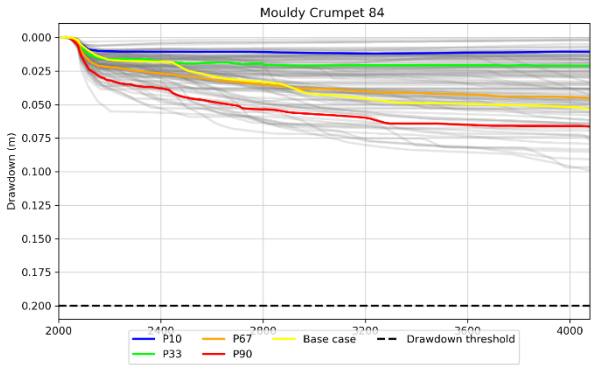
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 83
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 84
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
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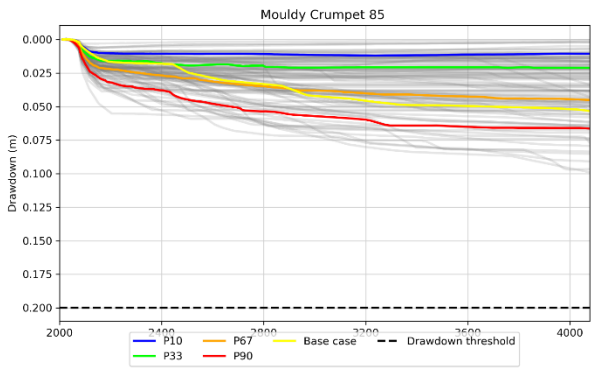
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 85
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
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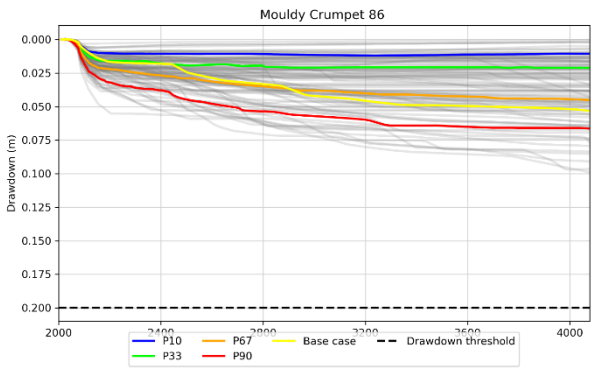
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 86
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
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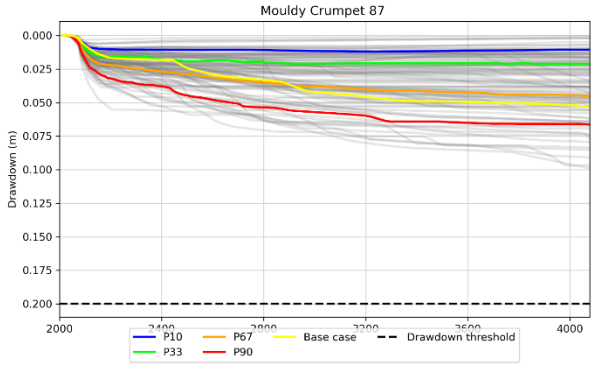
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 87
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
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2000
2400
2800
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4000
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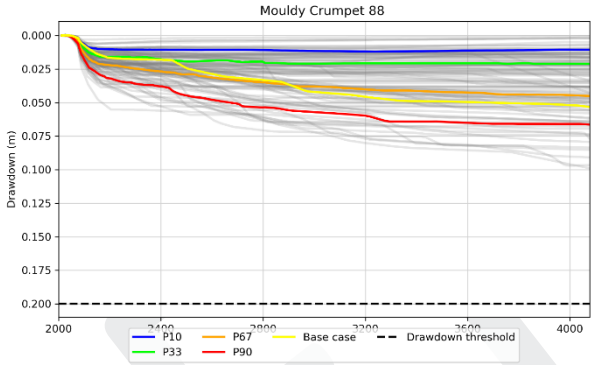
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 88
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
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2000
2400
2800
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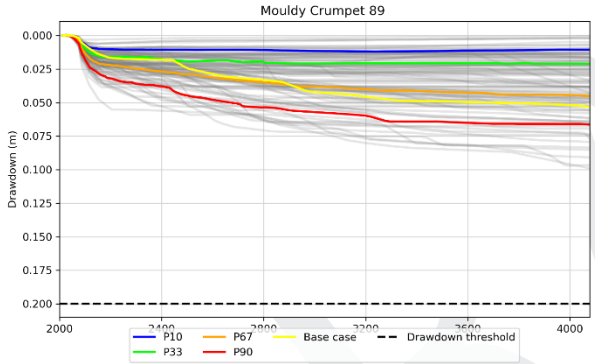
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 89
Drawdown (m)
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0.050
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2000
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2800
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3600
4000
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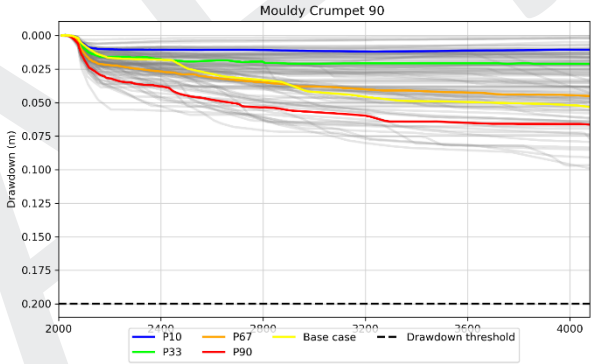
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 90
Drawdown (m)
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0.050
0.075
0.100
0.125
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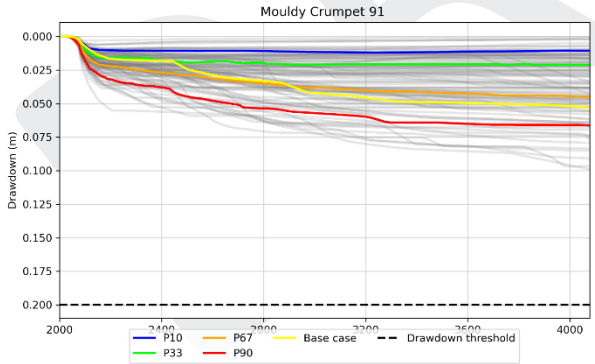
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 91
Drawdown (m)
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0.025
0.050
0.075
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2800
3200
3600
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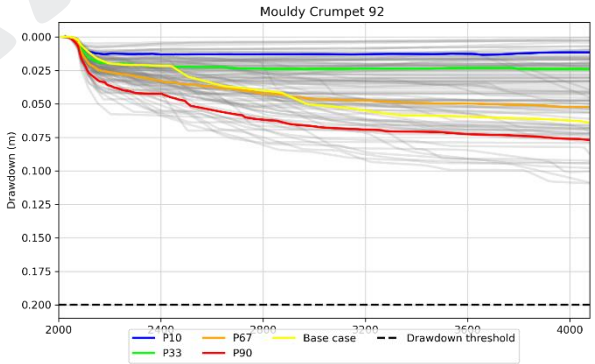
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 92
Drawdown (m)
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Base case
Drawdown threshold
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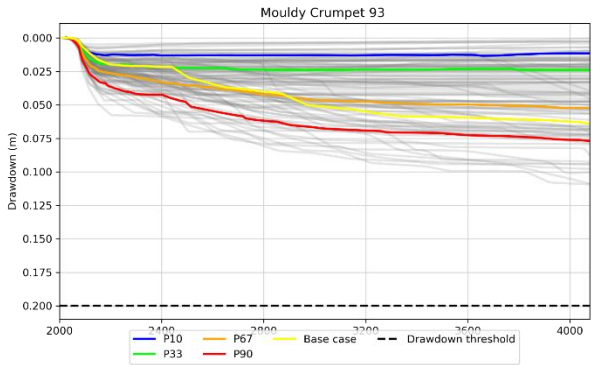
P90


Mouldy Crumpet 93
Drawdown (m)
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0.050
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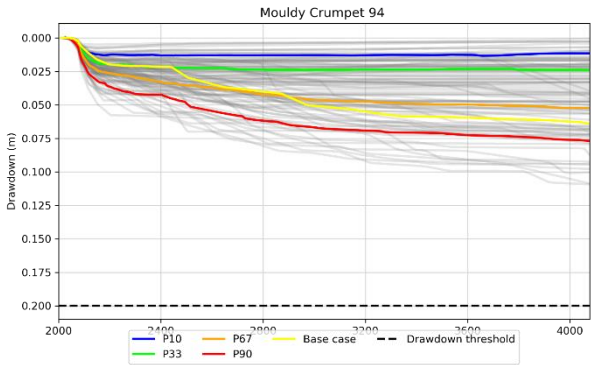
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 94
Drawdown (m)
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0.050
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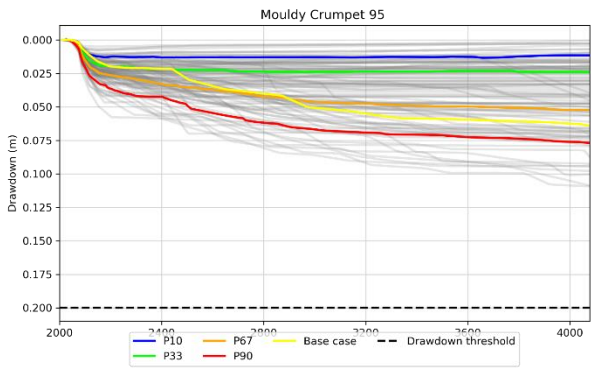
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 95
Drawdown (m)
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0.050
0.075
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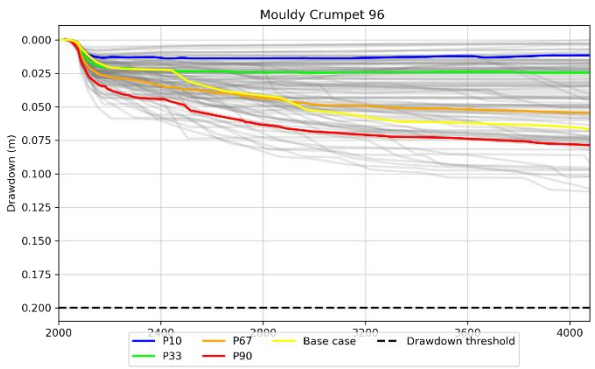
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 96
Drawdown (m)
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0.050
0.075
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Base case
Drawdown threshold
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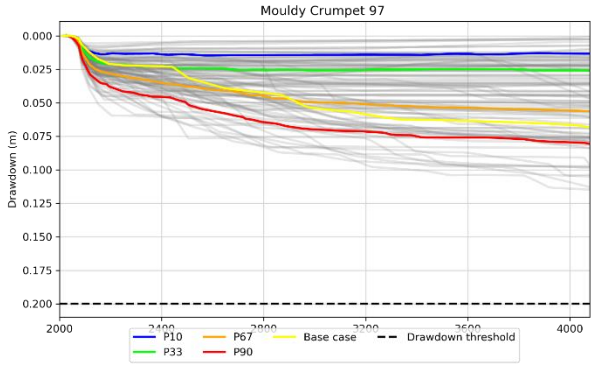
P90


Mouldy Crumpet 97
Drawdown (m)
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0.050
0.075
0.100
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Base case
Drawdown threshold
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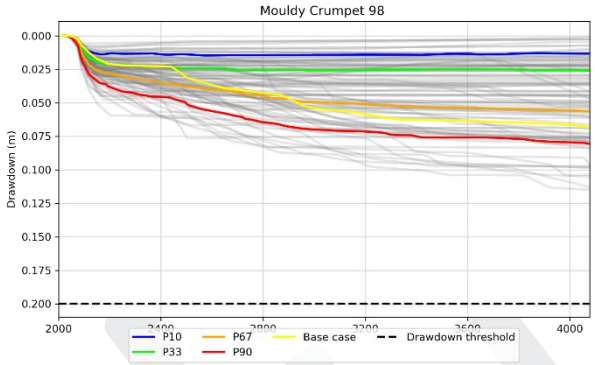
P90


Mouldy Crumpet 98
Drawdown (m)
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0.075
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Base case
Drawdown threshold
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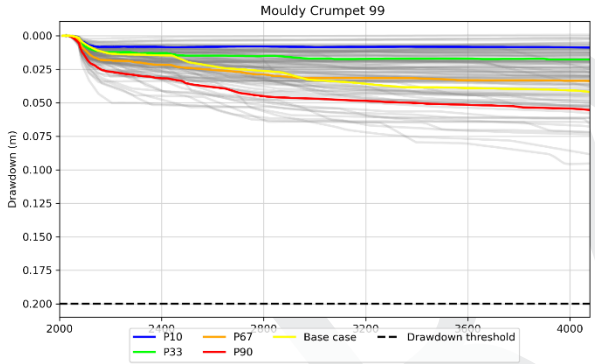
P90


Mouldy Crumpet 99
Drawdown (m)
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0.025
0.050
0.075
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Base case
Drawdown threshold
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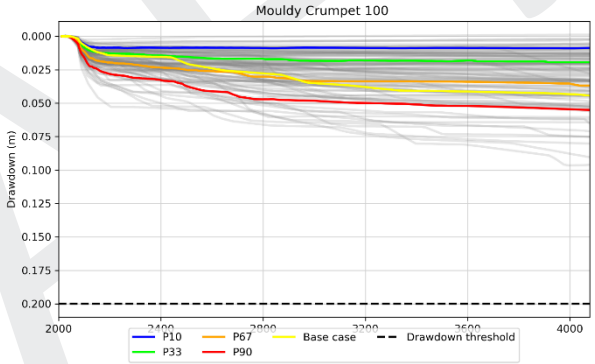
P90


Mouldy Crumpet 100
Drawdown (m)
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Base case
Drawdown threshold
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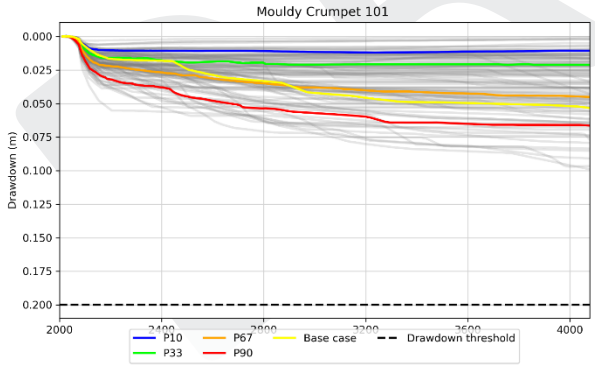
P90


Mouldy Crumpet 101
Drawdown (m)
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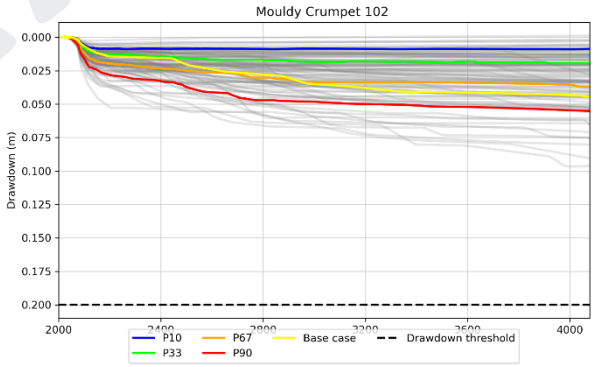
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 102
Drawdown (m)
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Base case
Drawdown threshold
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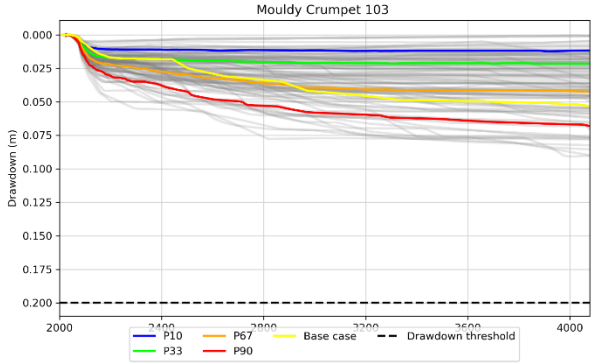
P90


Mouldy Crumpet 103
Drawdown (m)
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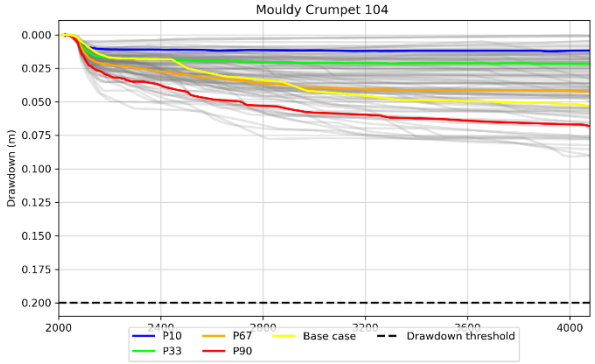
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 104
Drawdown (m)
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0.100
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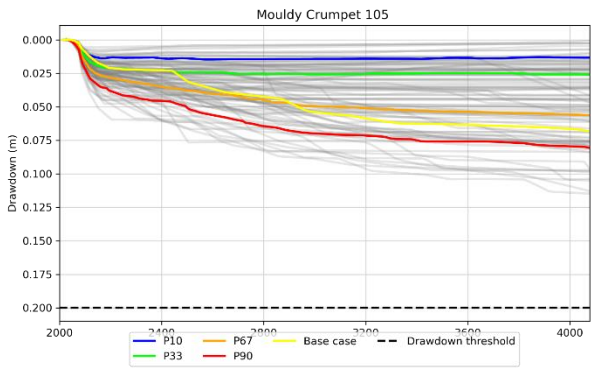
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 105
Drawdown (m)
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0.100
0.125
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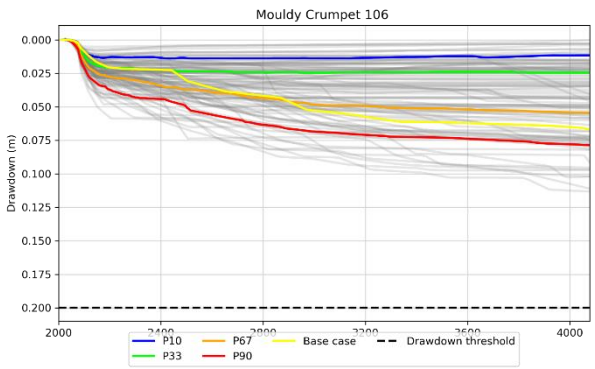
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 106
Drawdown (m)
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0.075
0.100
0.125
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2800
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3600
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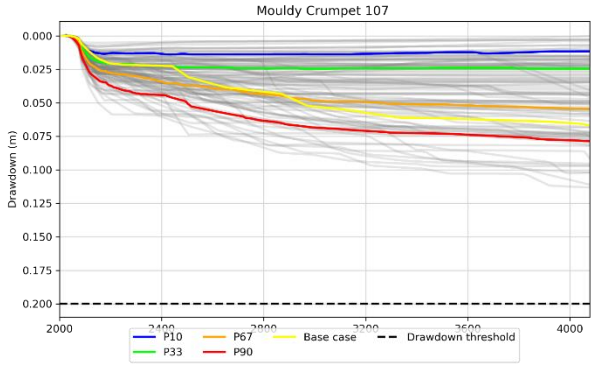
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 107
Drawdown (m)
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0.050
0.075
0.100
0.125
0.150
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2000
2400
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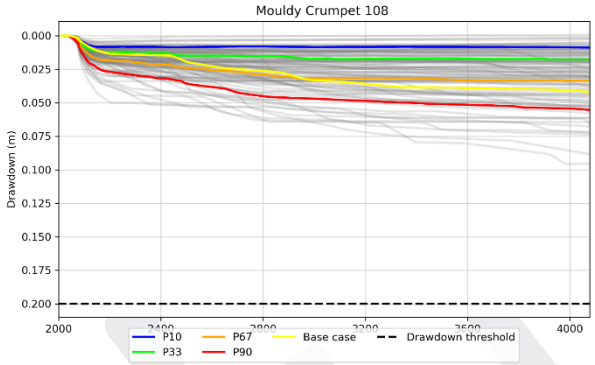
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90


Mouldy Crumpet 108
Drawdown (m)
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0.050
0.075
0.100
0.125
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2000
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2800
3200
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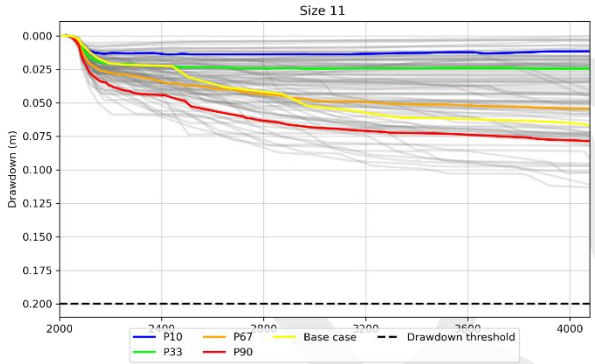
P10
P67
Base case
Drawdown threshold
P33
P90


Size 11
Drawdown (m)
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0.050
0.075
0.100
0.125
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2400
2800
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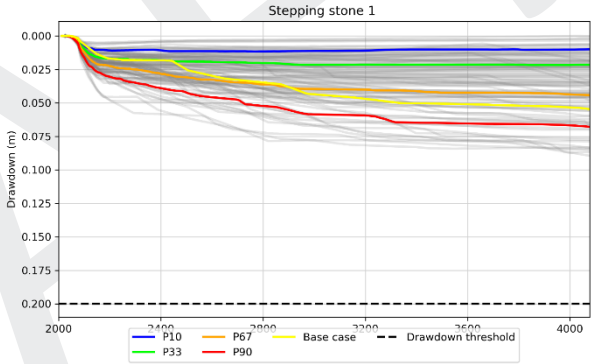
P10
P67
Base case
Drawdown threshold
P33
P90


Stepping stone 1
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
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2000
2400
2800
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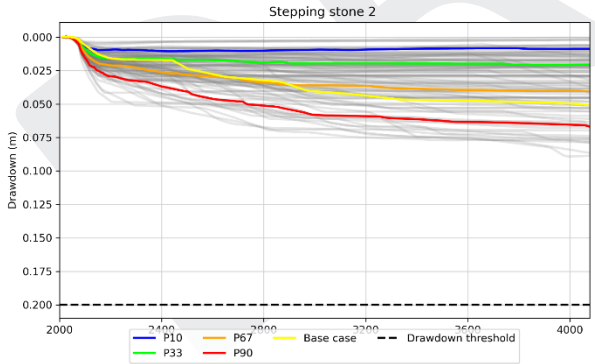
P10
P67
Base case
Drawdown threshold
P33
P90


Stepping stone 2
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
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2000
2400
2800
3200
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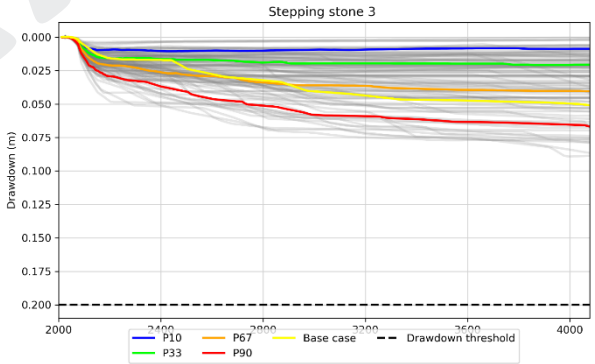
P10
P67
Base case
Drawdown threshold
P33
P90


Stepping stone 3
Drawdown (m)
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0.050
0.075
0.100
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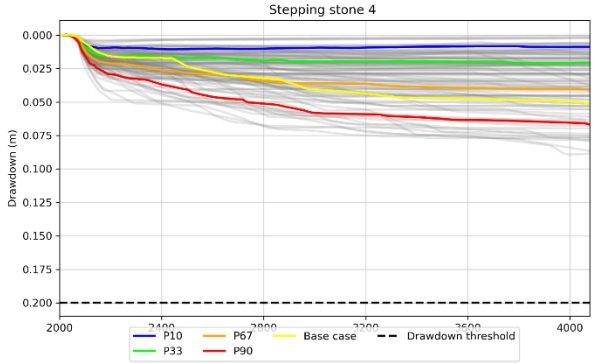
P10
P67
Base case
Drawdown threshold
P33
P90


Stepping stone 4
Drawdown (m)
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0.050
0.075
0.100
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0.175
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2000
2400
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3200
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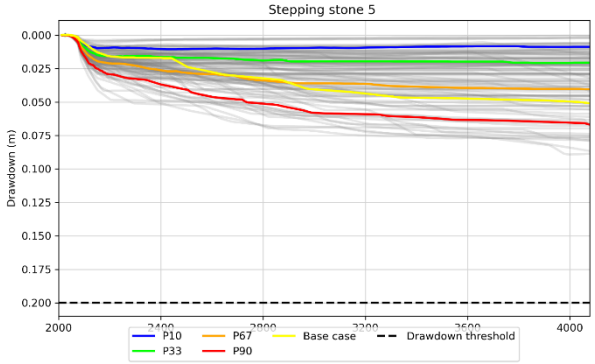
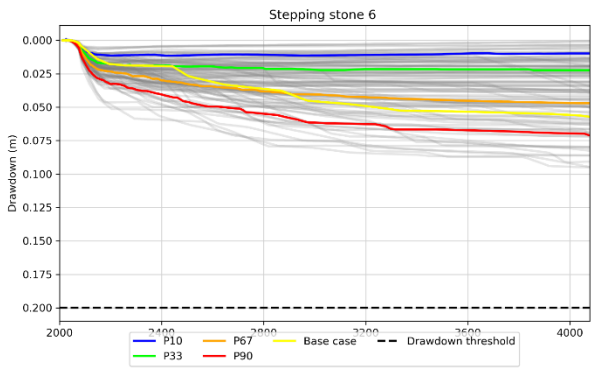
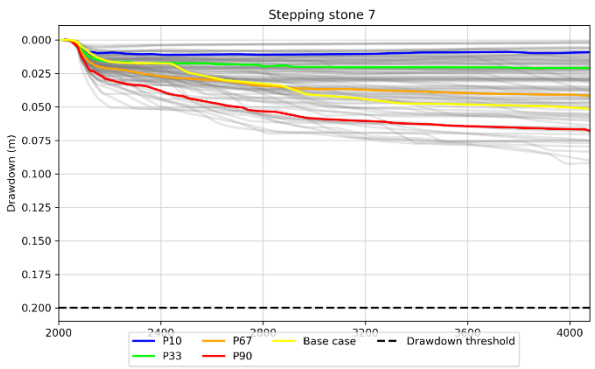
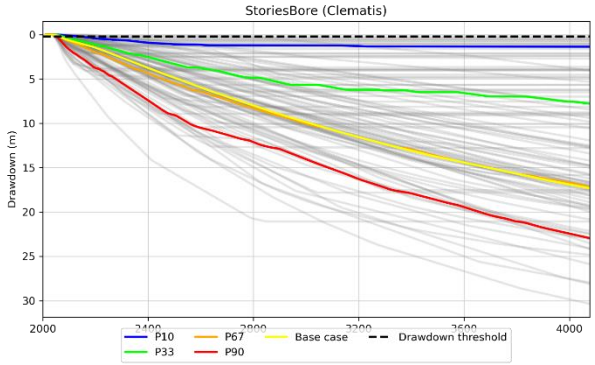
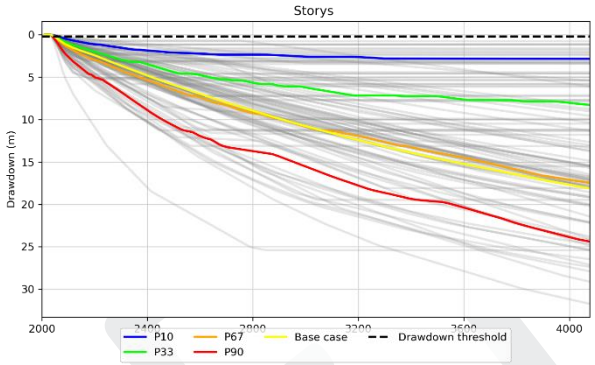
P10
P67
Base case
Drawdown threshold
P33
P90

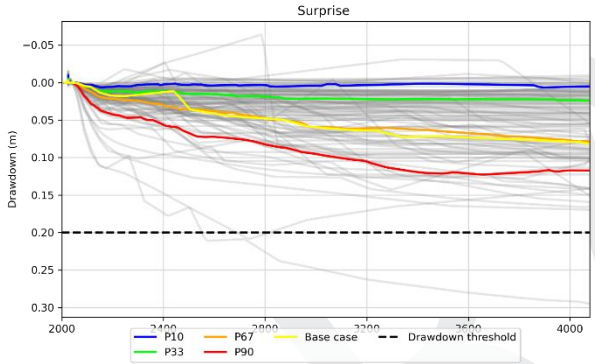

Stepping stone 5
Drawdown (m)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

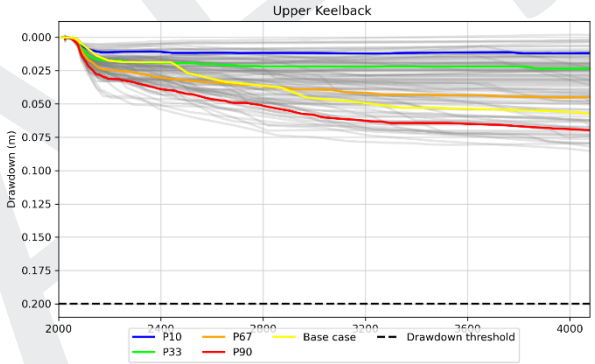

Stepping stone 6
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

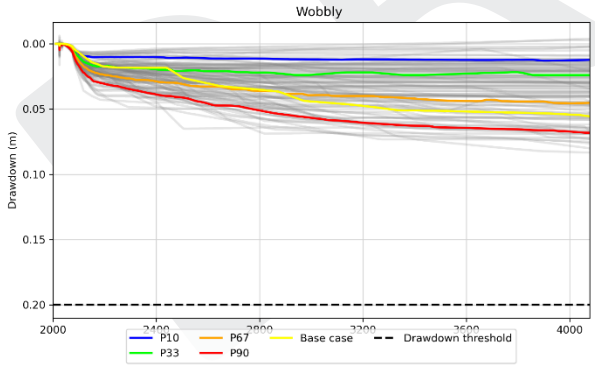

Stepping stone 7
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

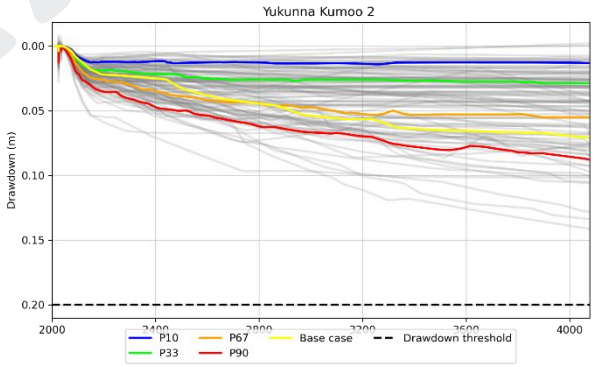

StoriesBore (Clematis)
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90

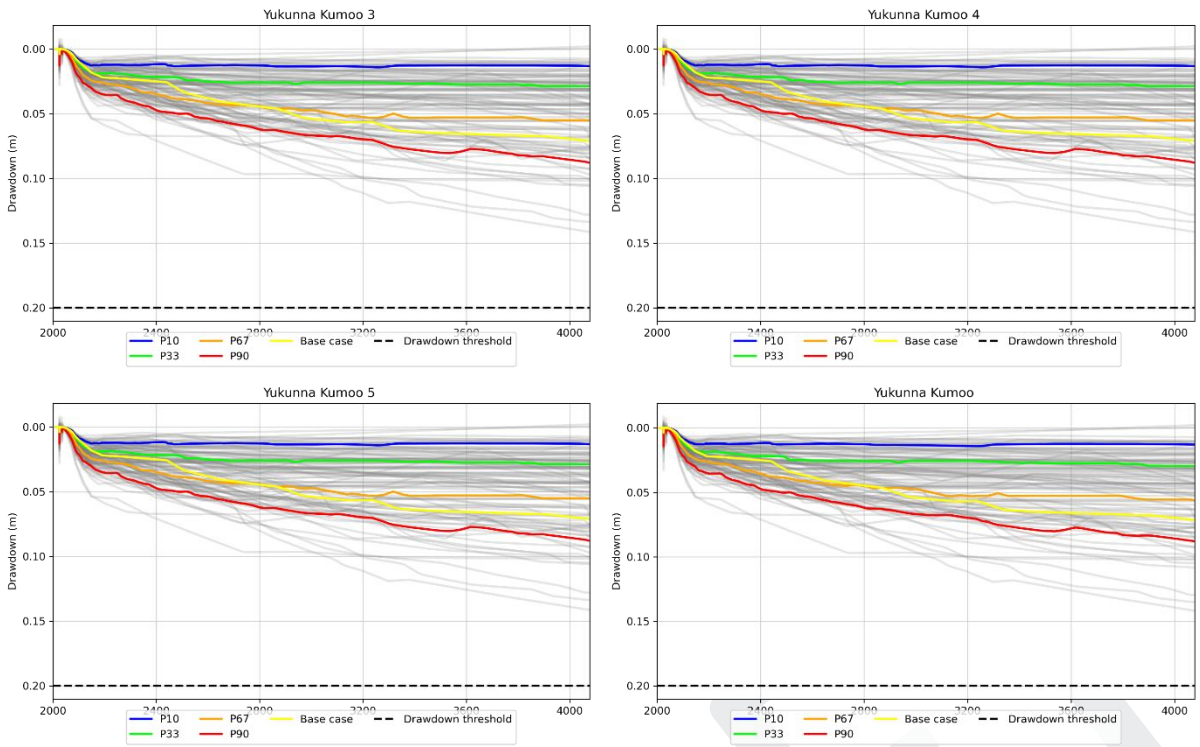

Storys
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90


Surprise
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90


Upper Keelback
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90


Wobbly
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90


Yukunna Kumoo 2
Drawdown (m)
P10
P67
Base case
Drawdown threshold
P33
P90


Yukunna Kumoo 3
Yukunna Kumoo 4
Yukunna Kumoo 5
Yukunna Kumoo
Drawdown (m)
0.00
0.05
0.10
0.15
0.20
2000
2400
2800
3200
3600
4000
P10
P67
Base case
Drawdown threshold
P33
P90

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Appendix E

Hydrographs: SEIS A

EMM
creating opportunities

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Appendix F
Hydrographs: SEIS B

EMM
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Appendix G
Model peer review

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