APPENDIX I

Dawson South Model Report

Anglo American

Dawson South EA Amendment

Dawson South Model Report

Final

DX70004A22

March 2024

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1 INTRODUCTION

KCB Australia Pty Ltd (KCB) has developed a 3D numerical groundwater flow model for the Dawson South area (the Project) to support Anglo American Steelmaking Coal's (Anglo) application for an amendment of the Dawson South Environmental Authority (EA) EPML00657413, in accordance with the Environmental Protection Act 1994 (EP Act).

The modelling results presented in this Model Appendix have been used to assess the potential impact to water resources as a result of the Proposed activities associated with the Project.

This model used the calibrated model developed by KCB (2023) to support the Dawson Central and North PRCP as a starting point. Additional data provided by Anglo from ongoing monitoring and activities in the Dawson South area was included (as needed) to amend the existing model. This model was refined to include details of current and historical mining and the Proposed expansion of Dawson South.

The regional groundwater model previously developed by KCB for the Westside Coal Seam Gas (CSG) fields was also used as reference (where needed) to amend the existing model built to support the Dawson North and Central PRCP. This report also details the design basis for the groundwater modelling, including the purpose of the model, assumptions, and limitations.

1.1 Model Objectives

The objectives of the Dawson South Model were to develop a groundwater flow model that reasonably represents the groundwater system, and that predicts changes in the groundwater levels and flows that may be the result of the changes to the Dawson South operations. The current model was updated and refined to incorporate the data related to the proposed mine progression.

The objectives of the refined groundwater model were to predict changes in groundwater levels and flows that may be a result of all operations (e.g. Open pit operations, surface water infrastructure, and tailings – historical and Proposed), which can be used to inform the application of the EA amendment, in accordance with the Environmental Protection Act 1994 (EP Act) which includes the existing (i.e. currently approved) Dawson South mine plan. This mine plan involves:

- Reconfiguration and extension of the approved Pit 28 final void; and
- Alterations to the approved final landform, including addition of a new final void in Pit 25 and southward extension of the approved Pit 28 final void.

The extent and area of influence of groundwater level drawdown associated with the Proposed mine plan including the final voids have been assessed (change in groundwater flow pattern and potential for increased drawdown are considered to be quantities of greatest interest in terms of comparing the current Dawson South final landform with the Proposed final landform). The project location is shown in Figure 1.1 below.

The current and proposed mine plans are not expected to meaningfully differ during the operational period since the mining footprint and sequence have not materially changed and the same coal seams are targeted. The post-closure period with an altered Pit 28 and new Pit 25 final void pit lake represents the most likely period for differences in groundwater drawdown to occur.

1.2 Application of the Conceptual Model

The groundwater flow model is based on the hydrogeological conceptual model. This conceptual model is described in the Dawson South EA Amendment Report. A hydrogeological conceptual model is a descriptive representation of the groundwater flow system and stresses. The closer the conceptual model approximates the field situation, the more accurate the numerical model predictions (Anderson and Woessner, 1991). A conceptual model defines the current understanding of the key processes of the groundwater system with consideration of the influence of stresses (Barnett et al., 2012). The application of the conceptual model to the groundwater flow model required synthesis and description of the geology framework and consideration of the groundwater flow systems that are present within the vicinity of the Project.

The Dawson Mining Complex is located within the Bowen Basin, an Early Permian to Middle Triassic foreland basin that contains thick successions of shallow marine and non-marine sediments and volcanics as well as extensive Permian coal measures. The geological setting of the Project area is shown in Figure 1.2. The topography at the Dawson Mine Complex is flat and gently undulating as shown in Figure 1.3. The area generally slopes to the west.

Under natural conditions, groundwater flow rates are low, partly from the alluvial deposits adjacent to the surface water systems (Dawson River and ephemeral creeks such as the Lonesome Creek to the west of the mining area). Under natural conditions, rainfall recharge is low over the Tertiary and Permian outcrop areas, while the alluvial has higher recharge and may be fed by surface water in high flow periods along the Dawson River.

The average annual rainfall in the Dawson Mining Complex area is approximately 654 mm with rainfall during the summer months occurring on an average of 63 days per year. Long-term average annual evaporation (Morton lake evaporation) is around 1,752 mm (Silo data).

Notes
1. Topographic features sourced 250k series 3 Geoscience Australia.
2. Image courtesy of ESRI Online Community
3. Mining leases proviced by Department of Resources, 2021.
4. Highwall/Endwall pit crest extend features provided by client.

Figure 1.1 Project Location and Proposed Mine Design

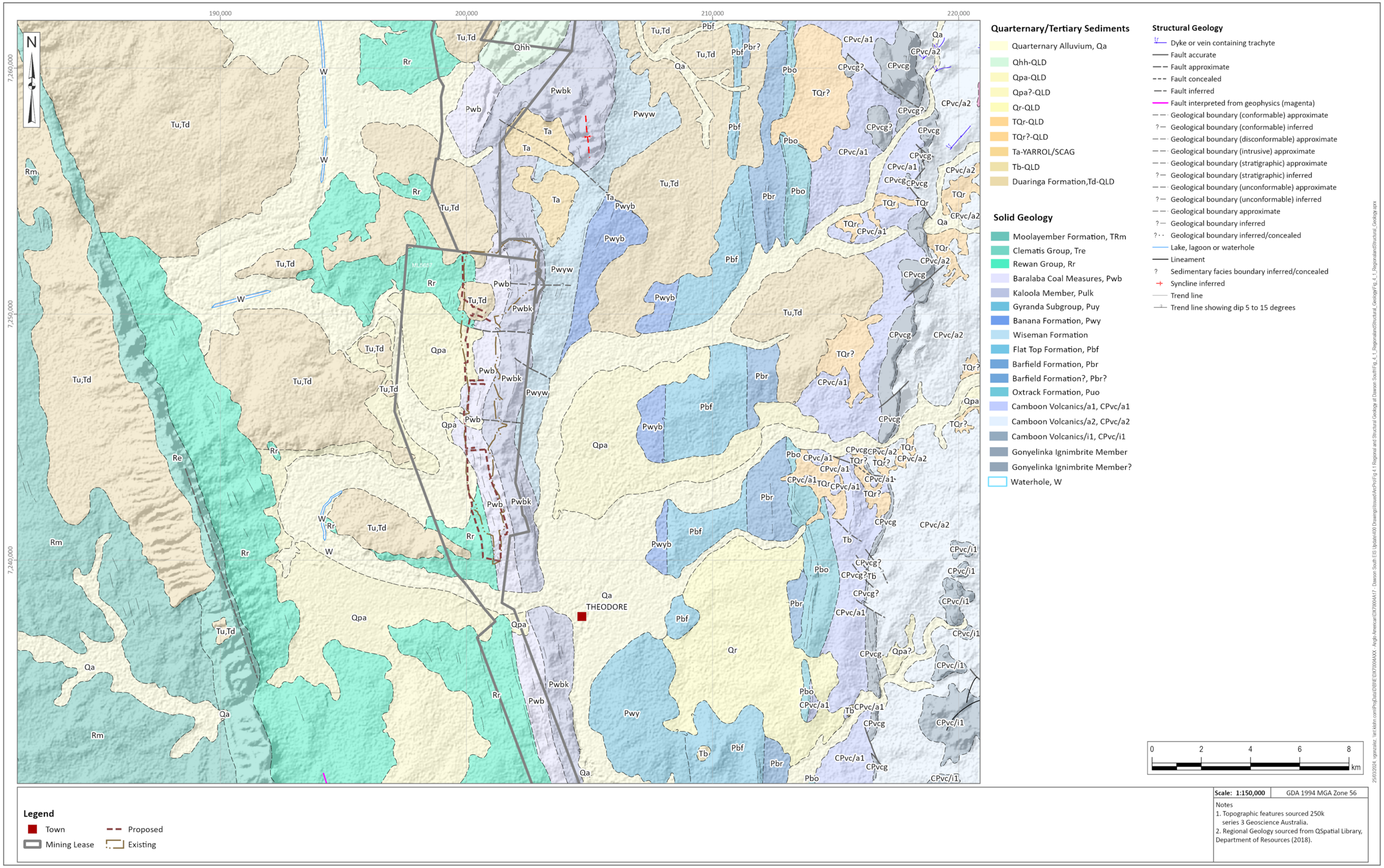
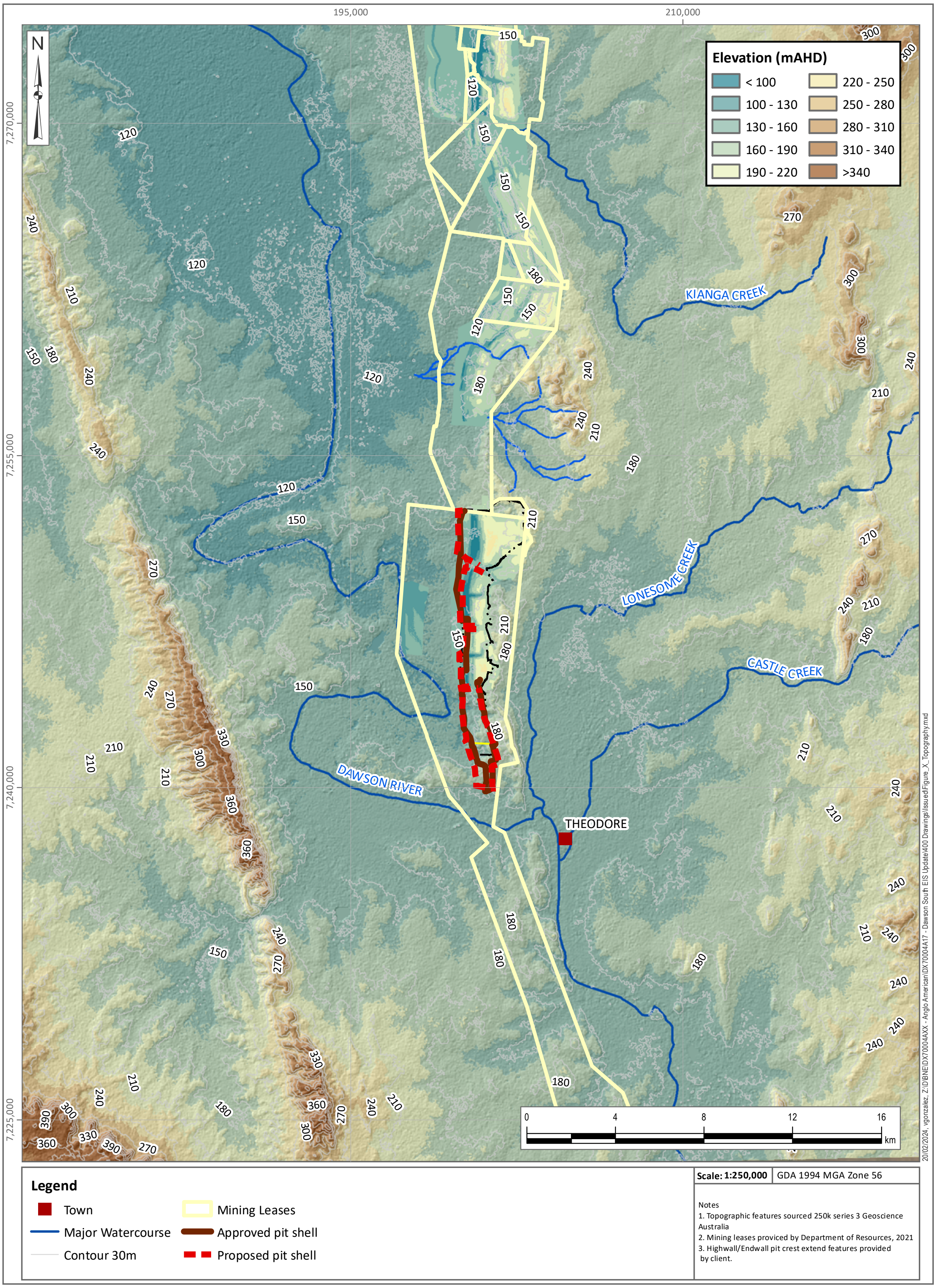


Figure 1.2 Regional and Structural Geology at Dawson South



Notes
1. Topographic features sourced 250k series 3 Geoscience Australia
2. Mining leases proviced by Department of Resources, 2021
3. Highwall/Endwall pit crest extend features provided by client.

Figure 1.3 Regional Topography and Drainage at Dawson South

2 MODEL DESIGN

2.1 Model Code Selection

The existing groundwater model developed by KCB for the Dawson central and north PCRP report was developed using MODFLOW-USG. This model was used as a starting point and amended to include the changes to the mining sequence in Dawson South.

MODFLOW-USG is an “unstructured grid” version of MODFLOW that can use an irregular grid structure with arbitrary cell/node connections. This enables focused grid refinement to occur in areas where detail is important, without the need for continuation of grid refinement to the extremes of the model domain. It also facilitates implementation of pinching-out layers and/or layer discontinuities within the modelled domain. This can greatly reduce the number of grid cells within the model domain and thus greatly reduce model runtimes. In addition, MODFLOW-USG implements an “upstream weighting” formulation of the groundwater flow equation that allows cells to dewater and re-saturate easily.

2.2 Units and Datum

The time unit for this model is day and the length unit is metre. In the horizontal plane, the model uses the GDA 1994 MGA Zone 55 projection, while the vertical datum is the Australian Height Datum (AHD) in metres. The Dawson mine reference system is at +2,000 m (2,000 metres above AHD). Conversions were made from the mine reference system to the Australian Height Datum.

2.3 Model Domain and Discretisation

The model domain was selected to adequately reflect the regional hydrostratigraphic units and prevailing surface water/groundwater interactions while also providing a platform for regional assessment of cumulative groundwater impacts from existing and operating projects in the area. The following hydrogeological elements were used as perimeter boundary conditions:

- North – “a distance far enough away from the mining area such that the model boundary does not influence the model results in the vicinity of the Project area”;
- East – aligned with the surface water catchment;
- South – Surat Basin extent and surface water catchment; and
- West – Dawson Range.

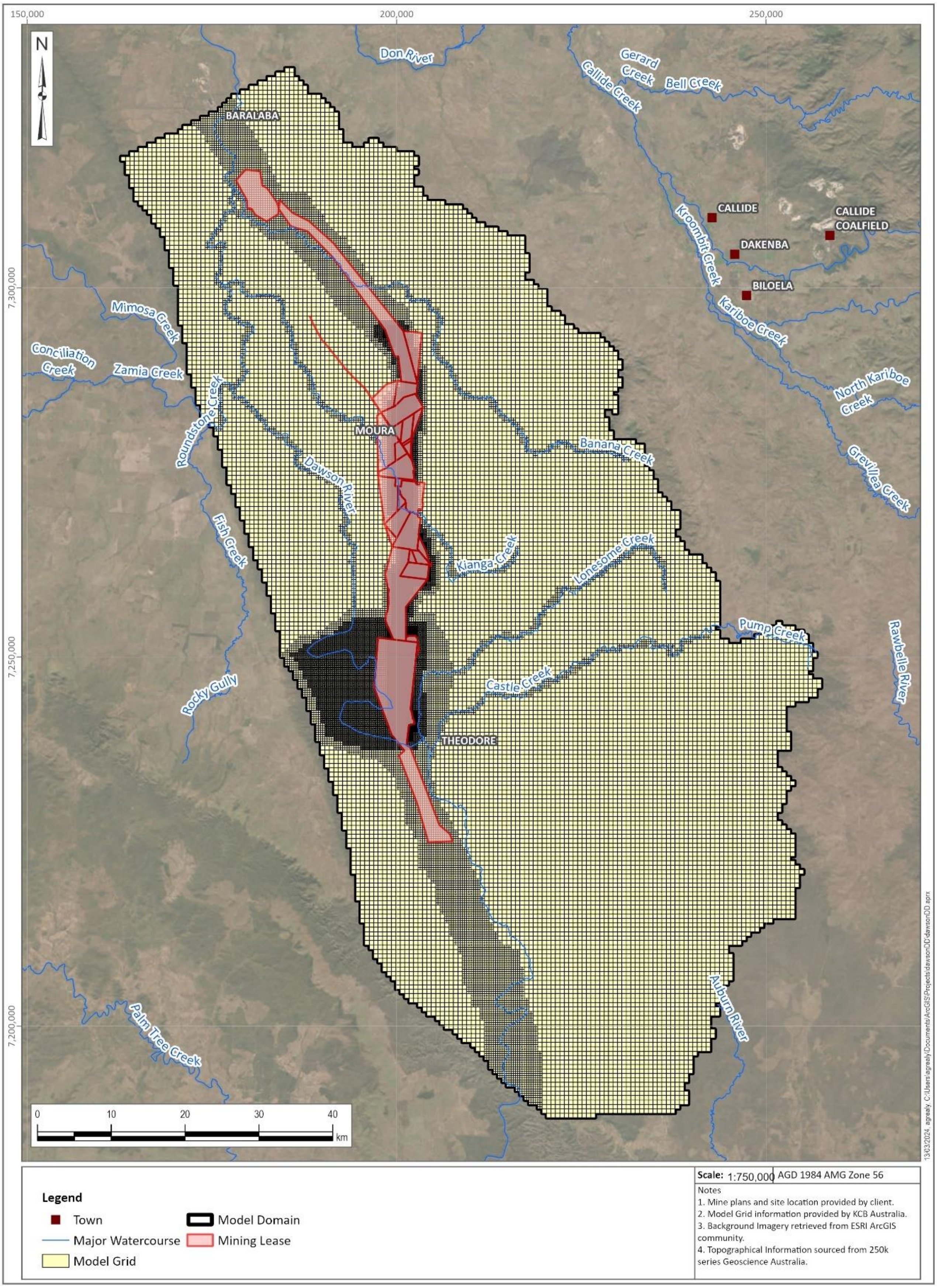
The model domain has a total area of approximately 7,110 km^2 covered by 762,971 active cells.

A quadtree refinement was applied to generate an unstructured grid. The Dawson Mining Complex was represented with a fine grid, while areas distant from the project site were represented with a coarser grid. The model grid size ranges from 75 m to 600 m. The resulting mesh developed for the model is presented in Figure 2.1.

2.3.1 Dawson South Model

Using the Dawson Central and North PRCP model, the grid was refined to accommodate the operations and pits in the Dawson South area. Within the footprint of Pit 25, 26, 27, 28N and around a 1,000 m outward buffer, the grid cell size was refined to 75 m. Between the west border and the southern pits, the grid was refined to 150 m to cover the Dawson River and alluvium aquifer.

The local coal seam stratigraphy was updated based on the Dawson South local geology and the stratigraphy merged to the larger domain PRCP model for Dawson Central and North.



Notes
1. Mine plans and site location provided by client.
2. Model Grid information provided by KCB Australia.
3. Background Imagery retrieved from ESRI ArcGIS community.
4. Topographical Information sourced from 250k series Geoscience Australia.

Figure 2.1 Numerical Model Domain and Mesh

2.4 Model Layers

The hydrostratigraphy of the study area was represented using eleven (11) model layers that are mainly discontinuous across the model domain. Multiple layers represent the Baralaba Coal Measures, including additional interburden layering to assist with the representation of the A, B, C, D and E coal seams. The model layers are outlined in Table 2.1.

Table 2.1 Model Layers Applied to the Model Domain

	Model Layer	Hydrostratigraphic Unit	Geological Age
Shallow aquifers	1	N/A - boundary layer to set up tailings heads	N/A
	2	Alluvium, tailings, rehabilitation and backfill material	Quaternary
	3	Tertiary sediments/Duaringa formation	Tertiary
Deeper units	4	Rewan Group - Upper	Triassic
	5	Rewan Group - Lower	
	6	Baralaba Coal Measures - A seam	Permian
	7	Baralaba Coal Measures - B seam	
	8	Baralaba Coal Measures - C seam	
	9	Baralaba Coal Measures - D seam	
	10	Baralaba Coal Measures - E seam	
	11	Undivided Basement unit	Permian and older units

2.5 Model Boundary Conditions

Boundary conditions are necessary for solution of the 3D groundwater flow equation that is implemented by MODFLOW-USG. They also provide a means by which auxiliary groundwater fluxes and stresses can be specified within the model. The following boundary conditions have been adopted in the model:

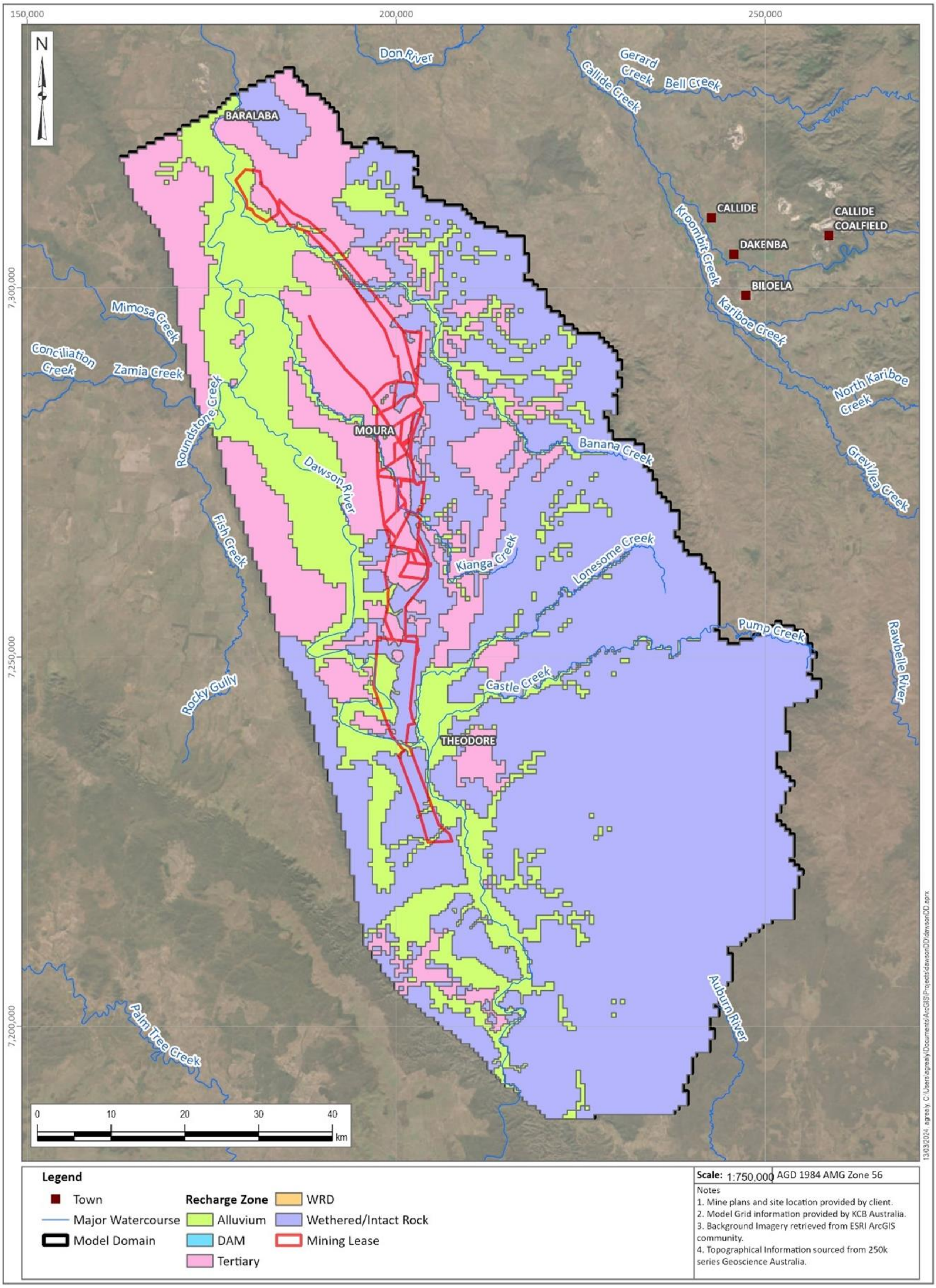
2.5.1 Recharge

Recharge was assumed to be effective recharge and was assigned to the uppermost layer of the model using the “MODFLOW Recharge package”.

Zones are defined by the extent/outcrops of different hydrostratigraphic units. The recharge zones and percentages calibrated in the model built for the Dawson Central and North Progressive Rehabilitation and Closure Plan (PRCP) were applied as initial values, as defined in Table 2.2 in areas shown on Figure 2.2. An extended recharge dataset, based on the inclusion of current and ongoing rainfall data was used for transient simulations.

Table 2.2 Model Recharge Rates

Modelled Recharge Zone	KCB (2021) Groundwater Model Percentage of Daily Rainfall %
Quaternary alluvium	0.6
Tertiary Sediments	0.2
Others	0.01



Notes
1. Mine plans and site location provided by client.
2. Model Grid information provided by KCB Australia.
3. Background Imagery retrieved from ESRI ArcGIS community.
4. Topographical Information sourced from 250k series Geoscience Australia.

Figure 2.2 Location of Recharge Areas in the Model Domain

2.5.2 Evapotranspiration

The MODFLOW Evapotranspiration package (EVT) was used to simulate evapotranspiration. The evapotranspiration given by KCB (2021) was applied as initial values. A uniform extinction depth was applied across the domain and set at 1.5 m below the natural surface, below which evaporative losses from the groundwater surface are zero. Where the groundwater elevation is above this level, water is removed from the system at a maximum rate of 365 mm/annum.

2.5.3 Drains

The drain package was also used to simulate open cut mining. Drains were placed in all layers above and including the target extraction layer. They were progressively switched on/off to reflect the mining progress, and the Time-Variant Materials (TVM) package was used along with the DRN package to reflect the rehabilitation and backfill of voids. The bottom elevations of the target coal seams in each open cut mining area were used to represent the depths of the drains. The amended and additional, current and proposed mining operation areas represented by drain cells included each of the Proposed pits Table 2.2).

Table 2.2 Drain Cells in Pits

Location	Existing operation area	Proposed operation area	Proposed operating Time
Dawson South	Pit 25	Pit 25	Y2022 – Y2030
	Pit 26	Pit 26	Y2022 – Y2025
	Pit 27	Pit 27	Y2022 – Y2027
	Pit 28	Pit 28	Y2027-2048

CSG extraction has been in operation near the project area for some time. CSG dewatering was implemented in the Dawson North and Central model using drain cells (DRN package). At the location of each CSG development well, drains were placed throughout the Baralaba Coal Measures. A starting reference head level for these drains was nominally 30 m above the top of the Baralaba Coal Measures at that location (KCB 2021). Drain conductance was refined during calibration.

2.5.4 River

For the Dawson River, MODFLOW's River Package was implemented to simulate interactions between the Dawson River and the alluvium during times of flow. Gauging station 130374A on the north boundary of the model was used, except where site-specific stage data was provided from Dawson upstream and downstream points.

Lonesome Creek and Castle Creek are located east of the South Dawson Project site and were represented as drain cells (DRN). Other ephemeral water courses in the vicinity of the project site were also represented using drain cells.

2.5.5 General Head Boundaries

The surface water storages (mine water storage and water dams) were represented using General Head Boundary conditions (GHB). The conductance and head of GHB boundaries were further calibrated with observed pit influx and piezometric data in the vicinity of Dawson South area.

Tailing dams were also represented by General Head Boundary (GHB package) passing through the tailing materials, which produces basal seepage to the foundation. The areas defined for the Central and North were also modelled as tailing dams before their closure (no tailings are stored at Dawson South) .

MODFLOW's General Head Boundary (GHB package) was implemented around the perimeter of the model domain. GHB was applied to all model layers in contact with the model boundary. This boundary type allows for the regional groundwater flow system to be reliably replicated at a sub-regional scale and ultimately improves the predictive capability of the model. It should be noted that GHBs do not significantly influence the model predictions in the vicinity of the project site due to the significant distances separating operations from the perimeter of the model.

Underground longwall mining was included in the Dawson North and Central PRCP model and was retained for the Dawson South Model.

2.6 Initial Material Parameters

Hydraulic conductivity (K) and storage parameters that were calibrated in the model built to support the Dawson Central and North Progressive Rehabilitation and Closure Plan (PRCP) were used as starting values for the refinement of the model in the Dawson South area (Table 2.3).

Table 2.3 Hydraulic Conductivity Values

Unit	Kh, m/d	Kv, m/d	Calibrated Specific Yield (-)	Calibrated Specific Storage (m-1)
Alluvium	1	0.1	0.01	3.24E-06
Tertiary sediments	0.2	0.02	0.01	3.26E-05
Rewan Group – upper	1.65E-03	1.65E-04	2.24E-03	1.00E-07
Rewan Group – lower	1.65E-03	1.65E-04	2.24E-03	1.00E-07
A seam	2.25E-02	2.25E-03	2.92E-03	9.00E-08
B seam	1.48E-03	1.48E-04	2.92E-03	9.00E-08
C seam	9.36E-04	9.36E-05	2.92E-03	9.00E-08
D seam	1.04E-04	1.04E-05	2.92E-03	9.00E-08
E seam	2.35E-02	2.35E-03	2.92E-03	9.00E-08
Model basement	1.06E-04	1.06E-05	1.71E-03	9.00E-08
Underground mine	1	0.1	0.01	3.24E-06

The accumulation of coarse spoil dumps creates zones of high permeability, as indicated by Edraki et al. (2019). For this reason, hydraulic conductivity values found for spoils in the literature were applied to the spoil dumps areas at Dawson South. Tests conducted by Fityus and Buzzi (2022) showed that most estimates for the saturated hydraulic conductivity of spoil based on physical measurement lie between 0.01 to 25 m/day.

JBT (2018) estimated a K for spoils at Dawson in saturated/unsaturated conditions, which was equal to 7x 10^{-2} m/day. A starting value of specific storage (Ss) for spoils equal to 10^{-5} 1/m, and specific yield (S_y) equal to 0.2 was used.

3 MODEL CALIBRATION

3.1 Calibration Process and Metrics

Calibration was conducted with the adjustment of model parameter values to achieve better replication of historical observations of the groundwater system. The outcome of the calibration process provides the initial conditions for transient predictive simulations used to assess changes to the groundwater regime through the operations and closure phases of the Project.

The calibration process included steady-state and transient calibration. The results of the steady-state calibration were used to define starting conditions for the transient calibration. Different stress periods were used to reflect the historical mining operations, which include underground mining, open pit operation and CSG extractions.

The calibration sequence consists of:

- A steady-state calibration with boundary conditions applied to replicate known mining development.
- Quarterly stress period-based transient calibration using steady-state calibration model outputs as the initial heads.

The North and Central Dawson PRCP calibrated model was the basis for inclusion of additional data provided by Anglo for Dawson South (landforms that reflect mine progression during life of mine until closure phase). The Dawson South Model was updated to accommodate the resizing of the pits in the south and the updated model was subsequently verified and calibrated.

The same steady-state and transient calibration stress periods applied in the North and Central PRCP model, which were: steady-state (pre-1963 condition), and transient calibration (1963-2022) were applied to the South Dawson Model. The duration of stress periods in the transient calibration will be yearly between 1963 and 2002, quarterly between 2003 and 2020, and monthly between 2021 and 2022.

The following model approaches were used to assess the calibration performance, based on the Australian Modelling Guidelines (Barnett et al. 2012):

- Model convergence.
- Water balance error <1%.
- RMS error <10 m.
- Scaled RMS of <10%.

3.1.1 Calibration Approach

Calibration of this model aimed to fix parameter estimation on the prevailing conditions over the period of October 1990 to March 2023 as this is the most reliable sequence of observation data available in the vicinity of the project site. Recordings for the period after 2014 are limited, with only a limited number of bores and one record for each year. Historical groundwater level data extracted from 95 monitoring bores located in the project area were used in the calibration. Figure 3.1 shows the distribution of calibration targets in the model area.

The calibration model run was initiated in steady-state with boundary conditions applied to replicate known mining progression at Dawson South. Following this initial model conditioning period, the model transitioned to transient mode for the remainder of the calibration period in which the same steady-state and transient calibration stress periods applied in the North and Central PRCP model. This was represented by a steady-state (pre-1963) condition, and transient calibration (1963-2022) applied to the South Dawson Model. The stress period duration in the transient calibration was yearly between 1963 and 2002, quarterly between 2003 and 2020, and monthly between 2021 and 2022. This stress period length was sufficient to allow for seasonal climatic variations to be considered and to represent the associated mine development within the model.

Automatic parameter optimisation was implemented with the use of PEST. PEST is a powerful tool, applied to provide rapid feedback on the adequacy of the conceptual model. PEST reports where limits on particular parameters, or groups of parameters, are required to be reached to achieve a better model calibration and/or where increased scrutiny on the field(s) and model data supporting the parameter limit(s) is required.

3.1.2 Calibration Targets

A total of 95 monitoring bores located in the project area were used to assess the calibration dataset, which included the monitoring of groundwater levels between October 1990 and March 2023. Figure 3.1 shows the distribution of monitoring bores at Dawson South.

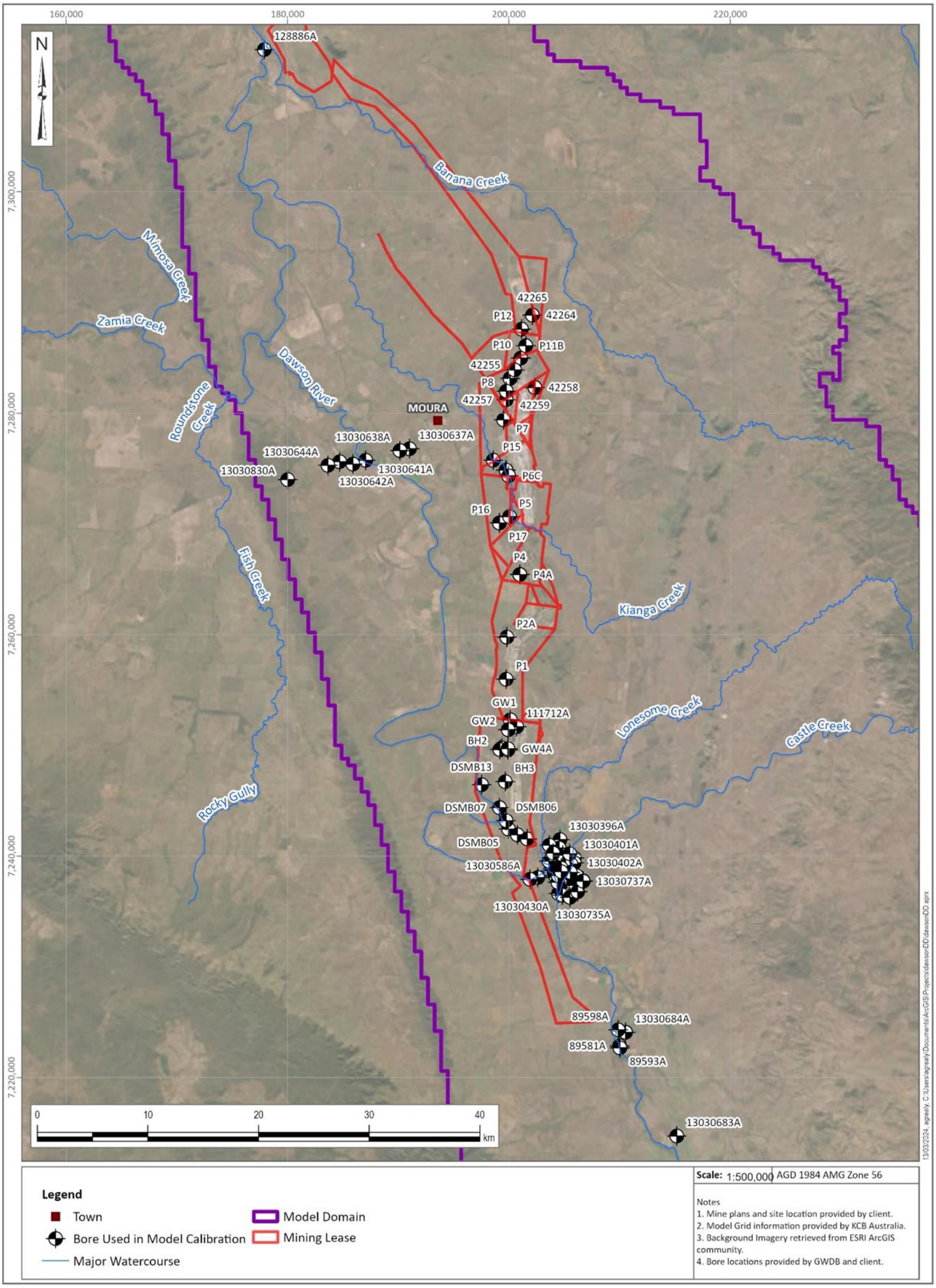


Figure 3.1 Transient Model Calibration Targets

3.2 Calibration Hydrographs

Selected calibration hydrographs, demonstrating the correlation between modelled and measured observations achieved through the calibration process, are shown in Figure 3.2 to Figure 3.7. The transient model simulation successfully matches observed groundwater level trends identified in the groundwater level monitoring records. The model calibration is considered robust and adequate for undertaking subsequent predictive simulations. Calibration in the shallow deposits (alluvium and Tertiary sediments) was considered important, as this formation is most likely to represent/reflect potential groundwater-related impacts.

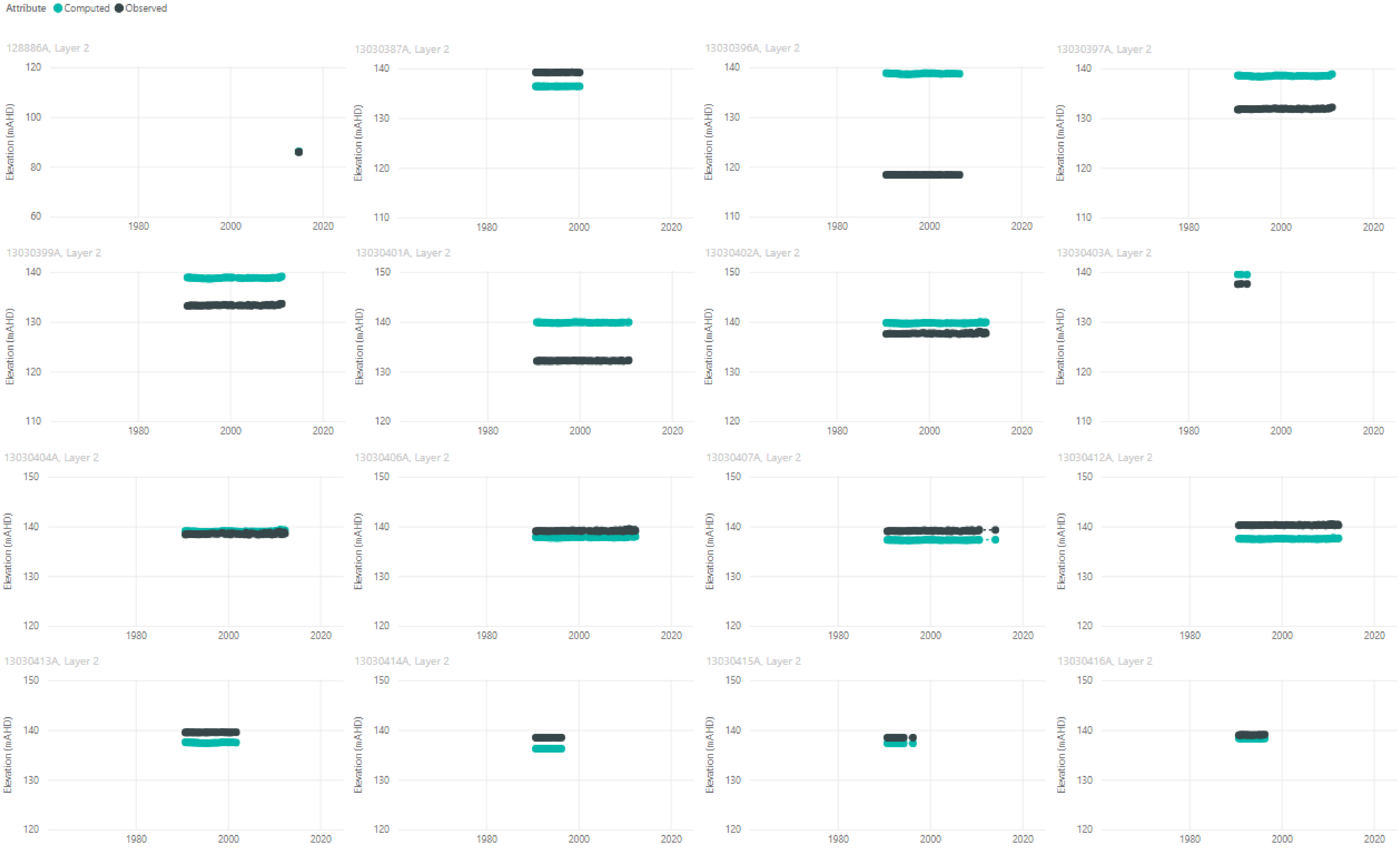


Figure 3.2 Transient Calibration Hydrographs – Layer 2

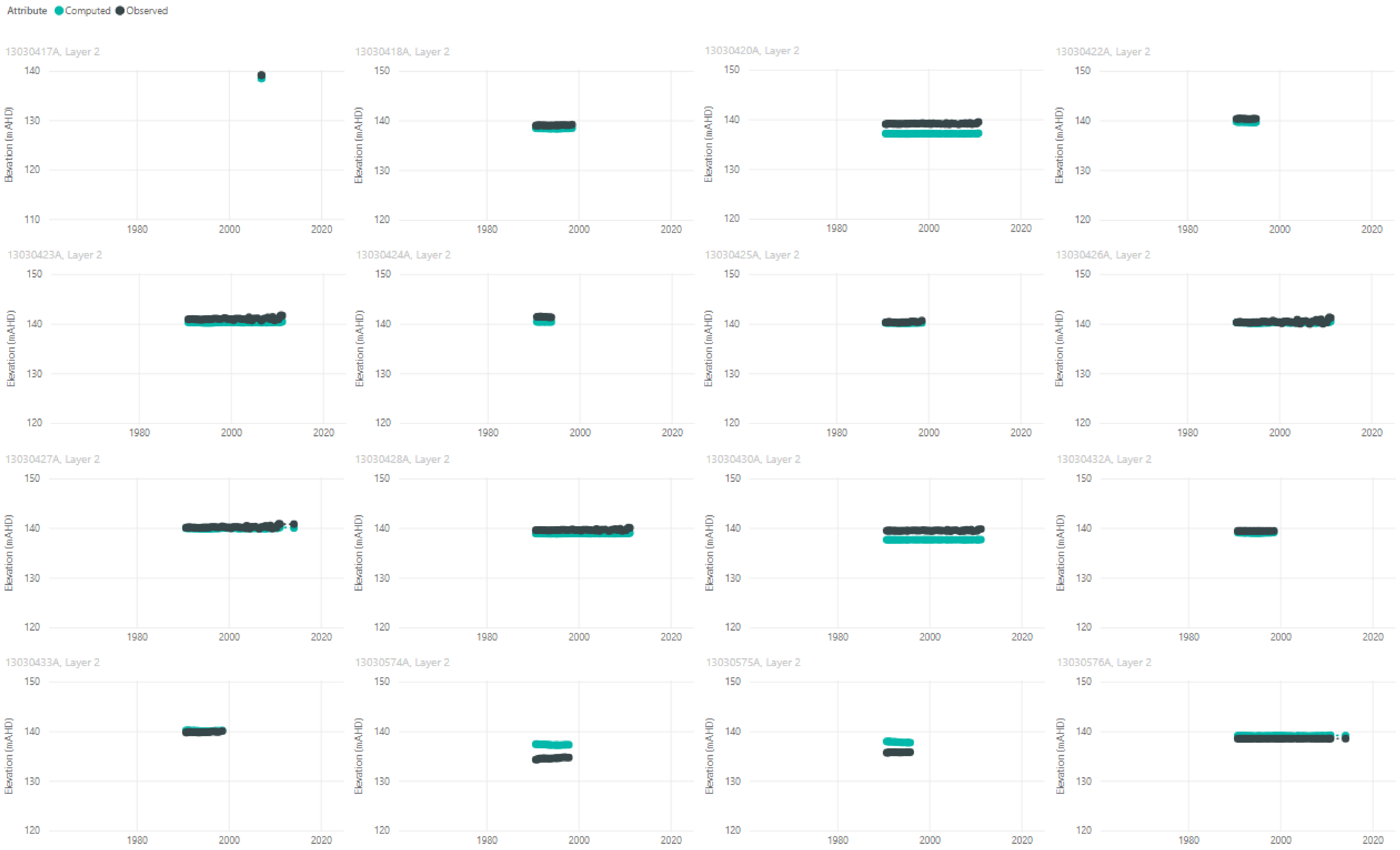


Figure 3.3 **Transient Calibration Hydrographs - Alluvium**

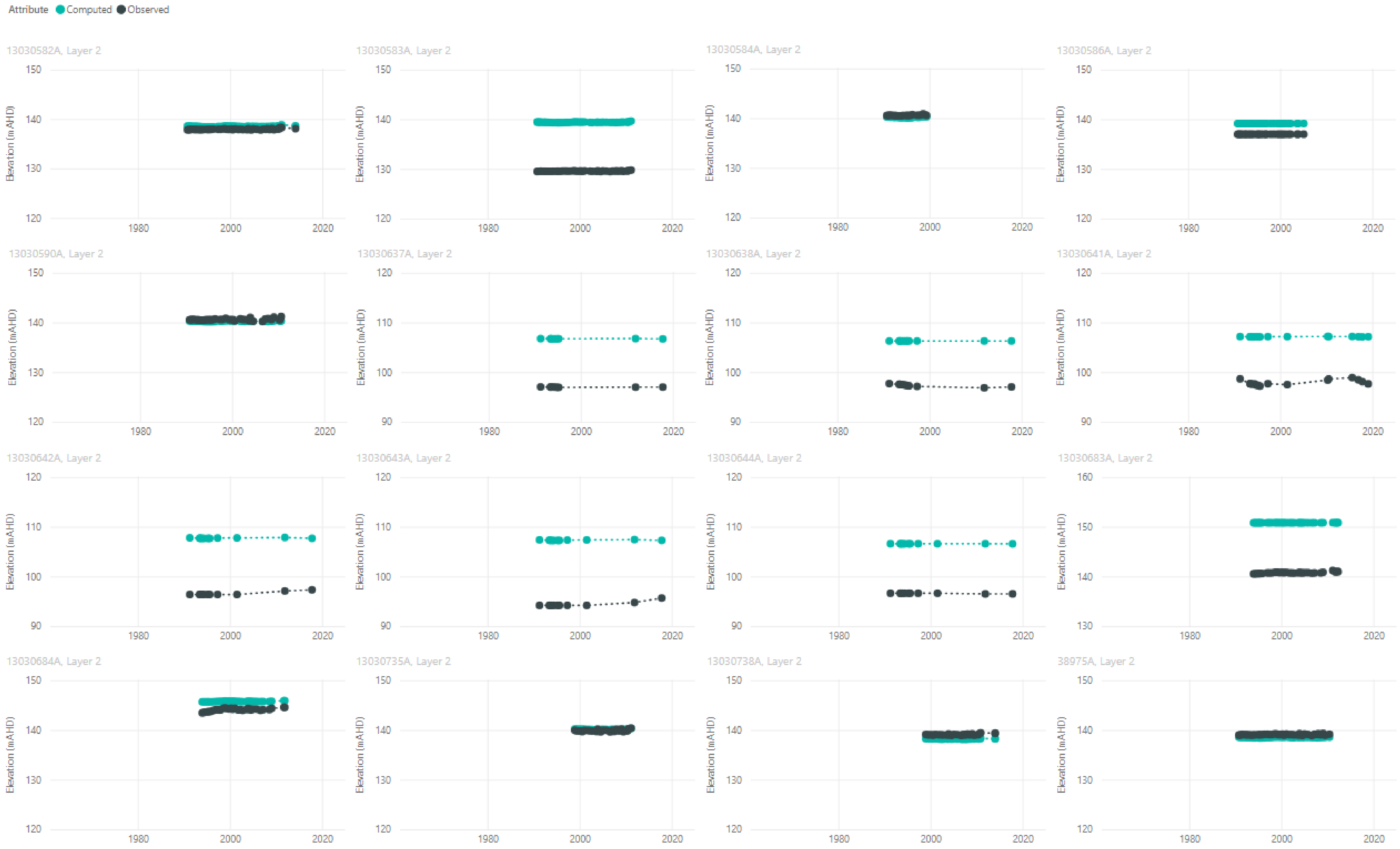


Figure 3.4 Transient Calibration Hydrographs - Alluvium

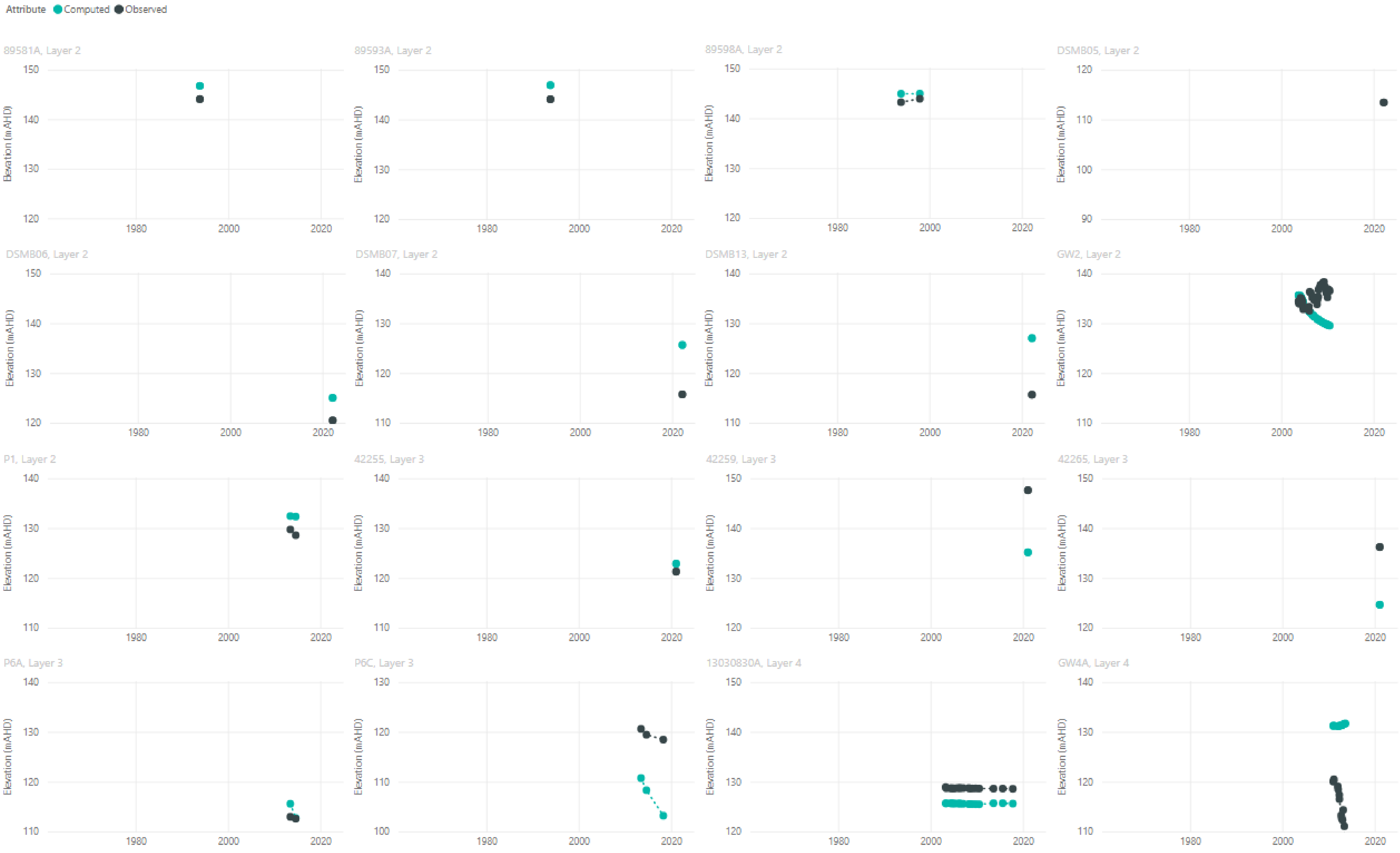


Figure 3.5 Transient Calibration Hydrographs Alluvium and Triassic Sediments

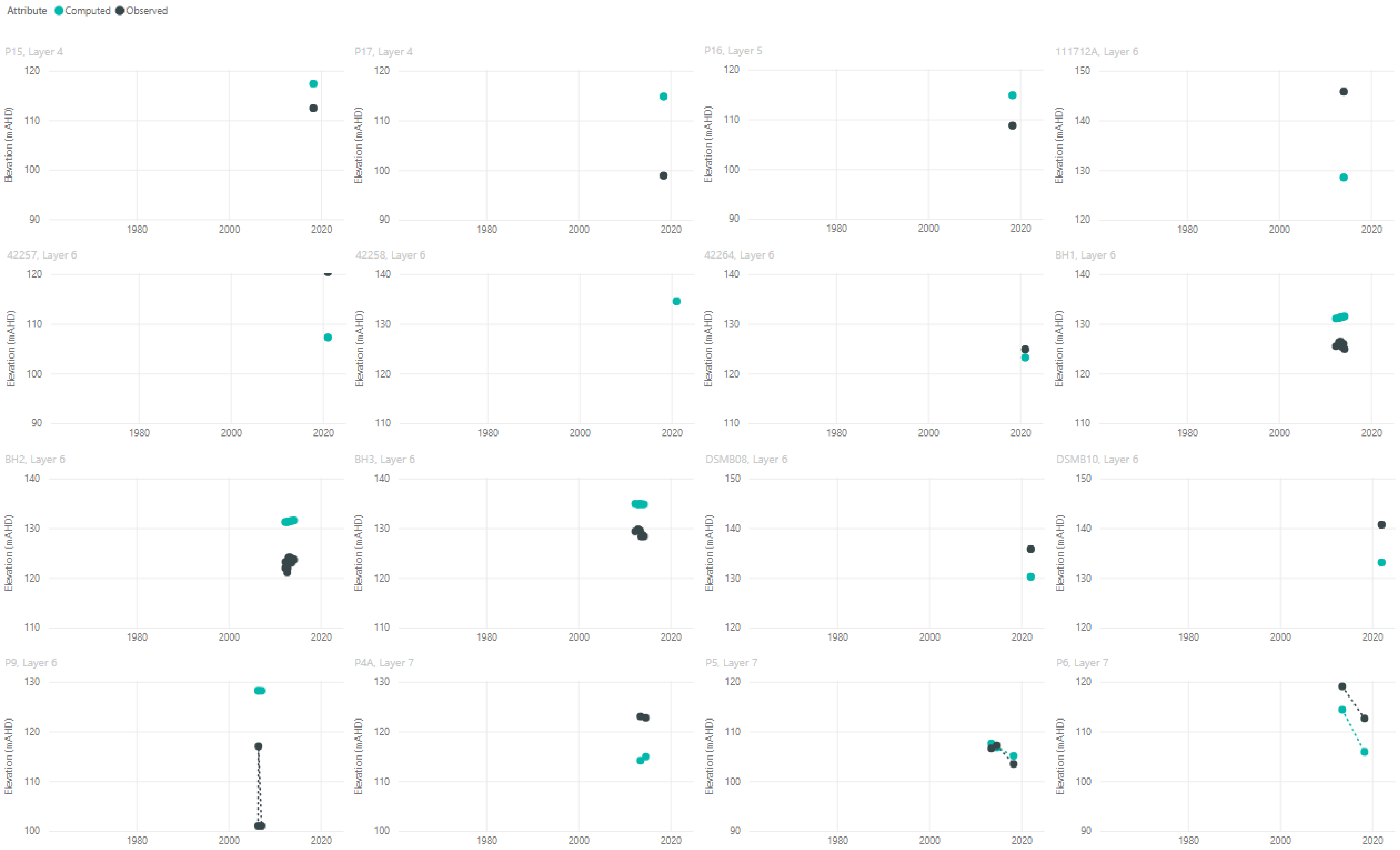


Figure 3.6 **Transient Calibration Hydrographs – Triassic Sediments and Upper Coal Seams**

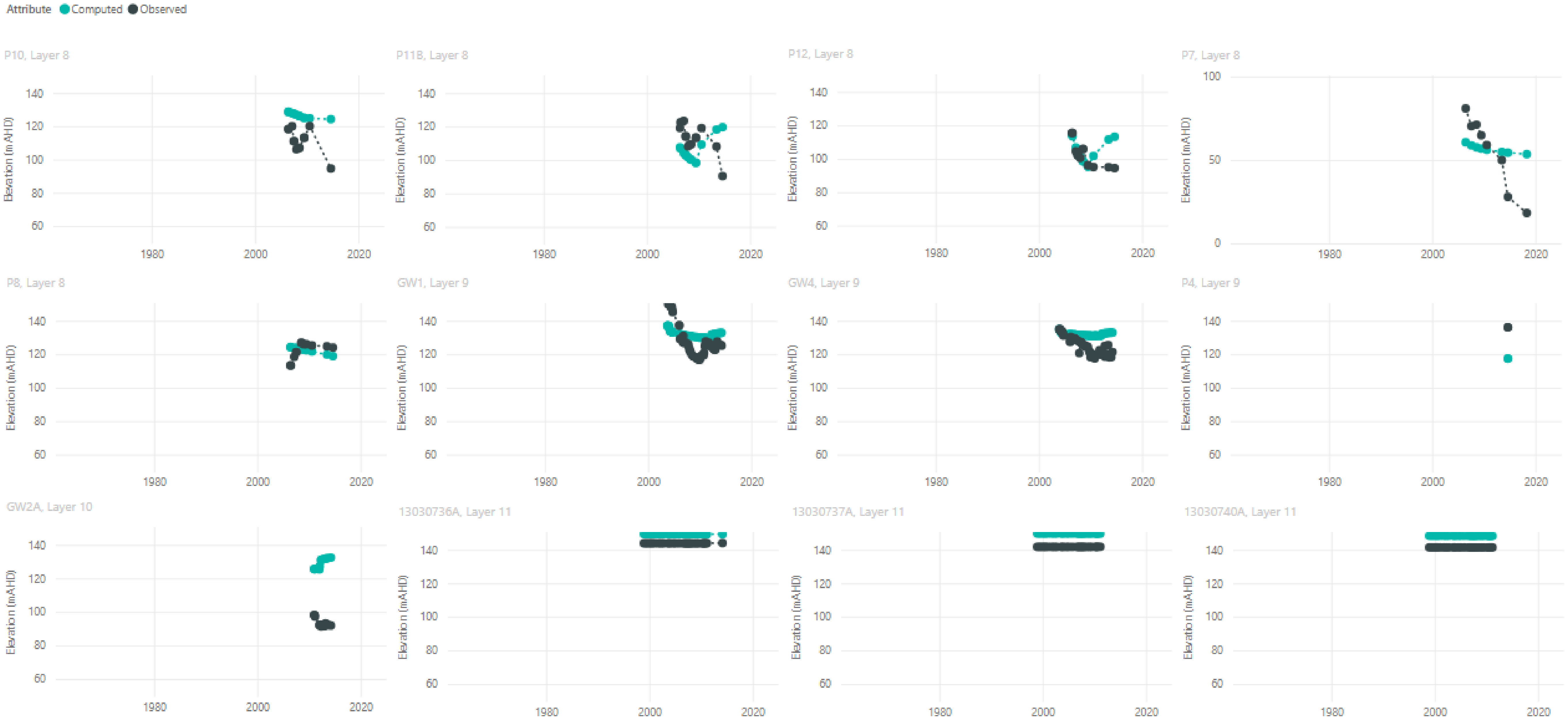


Figure 3.7 Transient Calibration Hydrographs – Permian Coal Seams

3.2.1 Calibration Metrics

A good transient calibration was achieved, and this is reflected in the calibration metrics as summarised in Table 3.1.

The scaled RMS of the observed groundwater levels vs simulated groundwater levels is less than the 10% limit recommended by the Australian Groundwater Modelling Guidelines (Barnett et al., 2012), which indicates that a good calibration has been achieved. It is also important to note that the calibrated model reproduces the groundwater flow processes in terms of matching recharge zones, discharge zones and balance in the system (replication of groundwater flow and vertical hydraulic gradients). The scatter plot of the observed vs the modelled hydraulic heads shows a good correlation with a recorded correlation coefficient of 0.86. The visual comparison of modelled against measured groundwater elevations is provided in Figure 3.8.

Table 3.1 Summary of Model Calibration Performance

Metric	
Number of Observations	1839
RMS Error (m)	6.97
Scaled RMS (%)	5.12 %
Mean Sum of Residuals	-2.14
Correlation coefficient	0.86

It should be noted that some divergence is noted in the calibration of selected bores in the deeper units. This appears to be related to a mismatch between the Proposed/scheduled timing of mining-associated dewatering and the field implementation. These discrepancies do not have a significant impact on the groundwater system above the shallowest mine seam (Layer 6 in the model). Observed from Figure 3.9 is that disregarding the data from layer 8 and layer 9 leads to an improved RMS Error of only 5.51%, suggesting that the calibration for the units of most interest to the potential impacts is even better (when data from model layer 8 and model layer 9 are excluded from the calibration comparison).

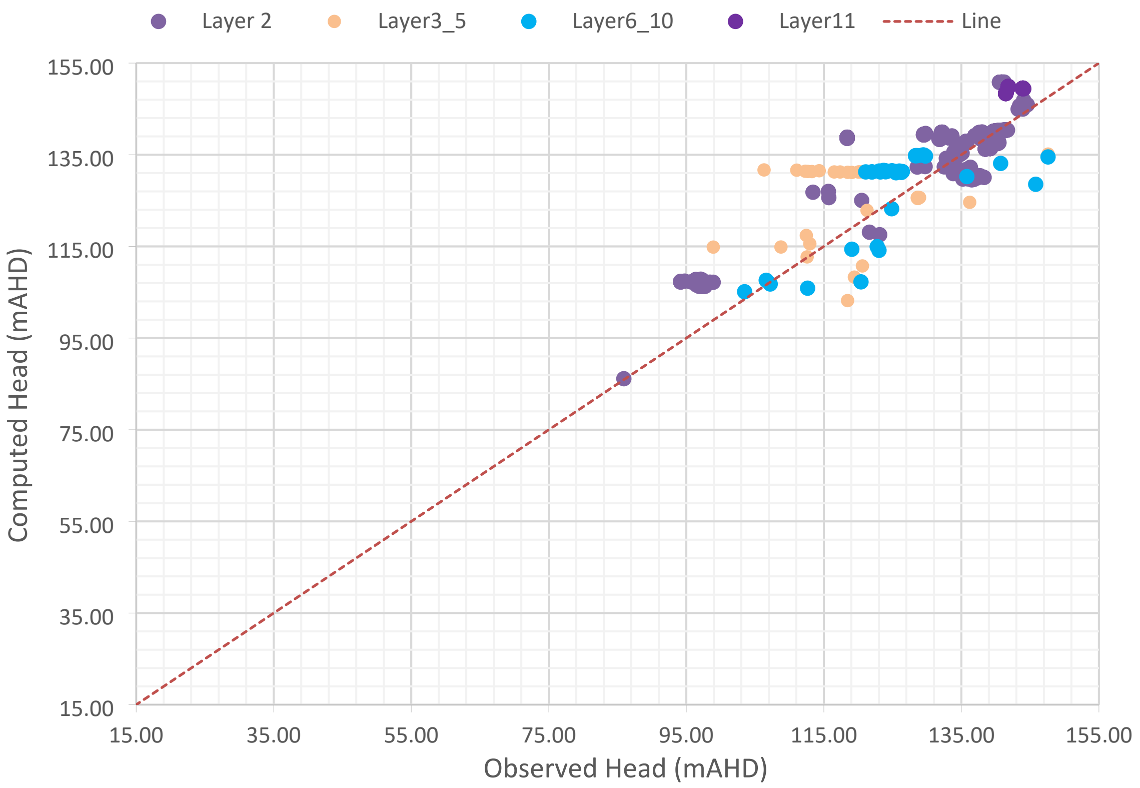


Figure 3.8 Scatter Plot of Observed vs Modelled Hydraulic Heads

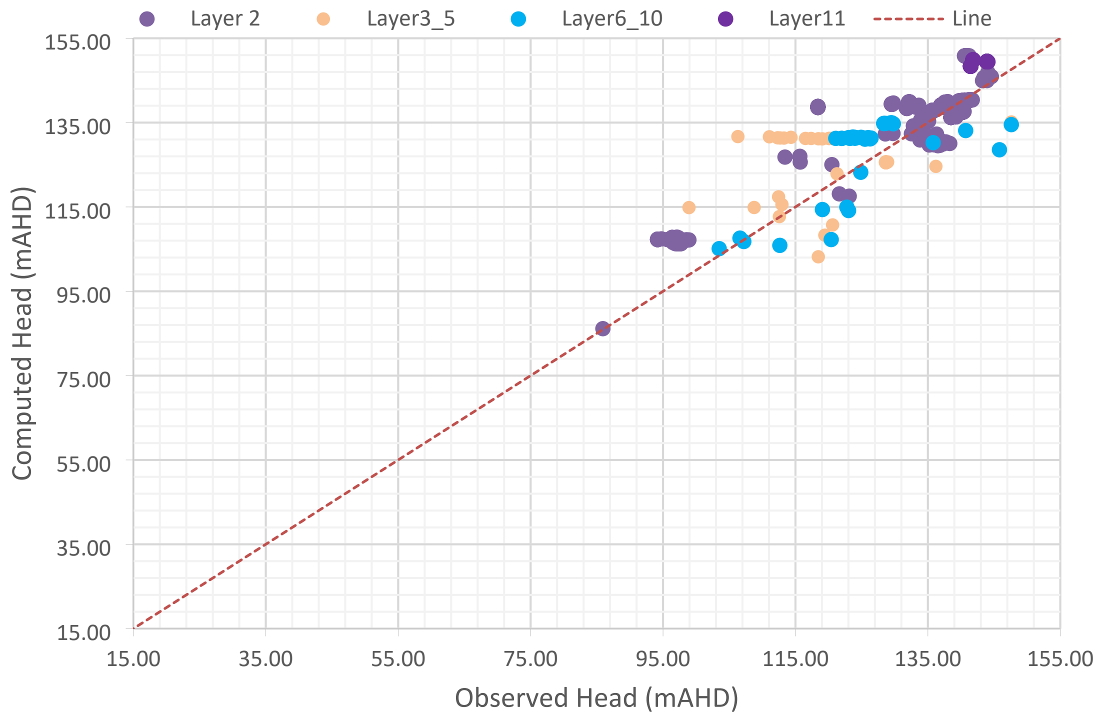


Figure 3.9 Scatter Plot of the Calibration without Layers 8 and 9

3.3 Calibrated Hydraulic Parameters

The calibrated hydraulic conductivity values and the calibrated storage parameters for each layer are presented in Table 3.2 while the calibrated recharge is provided in Table 3.3. These are largely unchanged in the shallower units (Rewan and above) but have been refined for the spoils and coal layers (including a slight increase in hydraulic conductivity for B, C and D seams).

Table 3.2 Summary of Calibrated Hydraulic Properties

Layer (Zone)	Geological Unit	Calibrated Kh (m/d)	Calibrated Kv (m/d)	Calibrated Specific Yield (-)	Calibrated Specific Storage (m^{-1})
1 (1)	N/A Boundary Layer to set up tailings heads	10	1	3.24E-06	0.1
2 (2)	Quaternary Alluvium	1	0.1	3.24E-06	0.01
3 (3)	Tertiary Sediments	0.2	1.00E-01	3.26E-05	0.01
4 (4)	Rewan Group (upper)	1.65E-03	1.00E-01	1.00E-07	0.00224
5 (5)	Rewan Group (lower)	1.65E-03	1.00E-01	1.00E-07	0.00224
6 (6)	A seam	2.25E-02	1.00E-01	9.00E-08	0.00292
7 (7)	B seam	1.48E-02	1.00E-01	9.00E-08	0.00292
8 (8)	C seam	9.36E-03	1.00E-01	9.00E-08	0.00292
9 (9)	D seam	1.04E-02	1.00E-01	9.00E-08	0.00292
10 (10)	E seam	2.35E-02	1.00E-01	9.00E-08	0.00292
11 (12)	Spoils	10	1	1.00E-05	0.1
12 (13)	Underground mining areas	1.00E+00	1.00E+00	1.00E-05	0.2
13 (11)	Model basement	1.06E-04	1.00E-01	9.00E-08	0.00171

Table 3.3 Calibrated Recharge Rates

Modelled Recharge Zone	Percentage of daily rainfall
Quaternary Alluvium	0.6
Tertiary sediments	0.2
Others	0.001

3.4 Calibrated Water Balance

The mass balance error of the transient calibration model is the difference between model inflows and model outflows calculated by the model. An error of 1% or less is typically considered acceptable for a regional groundwater aquifer system (Anderson and Woessner 1991).

The water budget and mass balance error for the steady-state and transient calibrations are presented in Table 2.10 and Table 2.11. The water balance error is less than 0.01%, which indicates that convergence of the numerical solution of the groundwater flow problem was achieved. Details are provided in Model Appendix II.

Table 3.4 Calibrated Water Balance – Steady-State

Steady-State	Inflow (m^3/d)	Outflow (m^3/d)
Drain	0.0	32.51
ET	0.0	25650.97
GHB	383.35	11.18
Recharge	24856.31	0.0
River	3257.63	2802.76
Mass balance error	<0.01%	

Table 3.5 Calibrated Water Balance – Transient Calibration

Transient State	Inflow (m^3/d)	Outflow (m^3/d)
Storage	594.63	25800.84
Drain	0.0	1439.36
ET	0.0	33434.36
GHB	365.35	10.87
Recharge	55483.92	0.0
River	4366.23	124.69
Mass balance error	<0.01%	

3.5 Model Classification

Barnett et al. (2012) developed a system to classify the confidence level of groundwater flow models based on the calibration process used and the predictive capability of the model. Three classes of model were developed: Class 1, Class 2 and Class 3. A Class 3 model has the greatest confidence level, and a Class 1 model has the least. Factors that are considered when determining model confidence level are:

- Data availability;
- Calibration procedures;
- Consistency between calibration and predictive analyses; and
- Stresses induced on the model.

The model outlined in this report is considered a Class 2 model because:

- A transient calibration was undertaken, and mining-induced groundwater trends have been replicated;
- Independent observations and calculations were used to support the calibration process; and
- The water balance error is less than 1%.

The model meets the criteria for a Class 2 model and exceeds the criteria for a Class 1 model. The model is therefore considered a suitable tool for assessing the potential groundwater impacts of the Project.