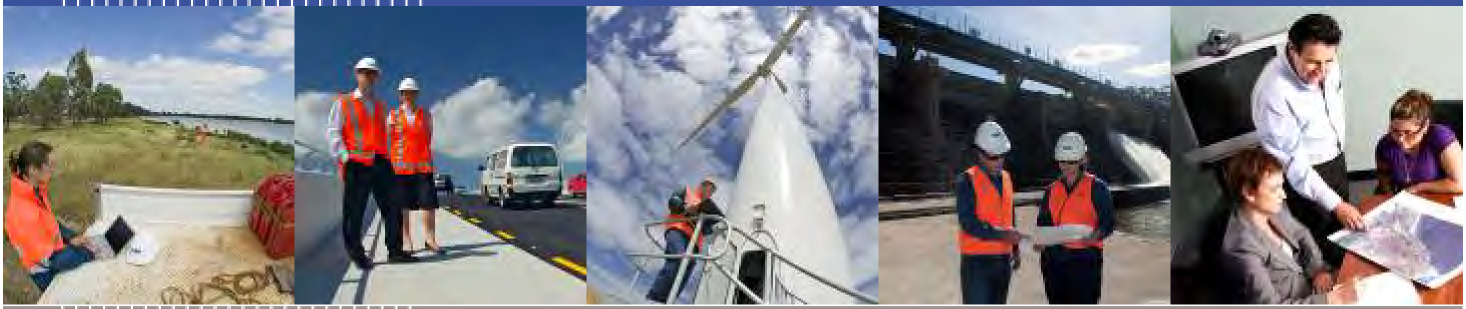

Report

Adani Carmichael Coal Project

Numerical Groundwater Model Peer Review

14 OCTOBER 2013

Prepared for

Adani Mining Pty Ltd

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42627082

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Executive Summary

URS was appointed to undertake an independent review of the numerical groundwater model, which was constructed and calibrated to assess the potential impacts of the proposed Carmichael Coal Project on the groundwater resources.

The review found a significant amount of site specific data has been collected by GHD and the report provides a summary of the field and laboratory analysis undertaken. The testing appears to have been carried out in a competent manner and the data analysis is sound. As a general comment, the field data could have been better integrated into the conceptual model to determine a set of preferred values and ranges for aquifer characteristics such as hydraulic conductivity and storage.

There is limited detail on the conceptualisation and conceptual hydrogeological model, which forms the basis for the numerical groundwater model. It is suggested that this should be improved to allow for increased confidence in the resultant model.

The model design and construction is appropriate and allows for the simulation of a multilayered complex hydrogeological system. URS obtained the MODFLOW-SURFACT model files which allowed for the running of the model. The model calibration allowed for a good correlation between measured and modelled steady-state groundwater level data. The calibration did, however, raise issues, including:

- The validity of the calibrated groundwater levels, i.e. do the modelled results still produce the same upward or downward vertical gradients.
- No storage calibration can be obtained from steady-state calibration so literature values were used. Validation of these data is required.
- The calibrated steady state model water balance indicates high recharge loss, which requires discussion.
- Hydraulic conductivity distribution across the layers is heterogeneous and needs discussion.

An evaluation of the model in terms of predictions and confidence was conducted. Several comments or questions have been identified, which need to be considered to allow for a better understanding of the modelling. These include:

- Cumulative percentage discrepancy > 1%.
- Stream leakage and baseflow.
- Model parameter variation due to longwall mining.
- Post-closure water balance

It is considered, based on the results of the review that additional details are required to best understand the decisions made during the modelling and allow for increased model confidence. A series of recommendations have been compiled to improve the predictive model performance.

Introduction

Adani Mining Pty Ltd (Adani) appointed URS Australia Pty Ltd (URS) to undertake an independent review of the numerical groundwater model, which was constructed and calibrated to assess the potential impacts of the proposed Carmichael Coal Project on the groundwater resources.

GHD Pty Ltd (GHD) conducted the numerical groundwater modelling on behalf of Adani utilising the MODFLOW-SURFACT software. URS received the input and output model files for evaluation and conducted a review of the groundwater data included in the draft Mine Hydrogeology Report, dated 26 July 2013 (GHD, 2013).

1.1 Objectives

URS were requested to undertake the model review in order to:

- Satisfy the requirements of the regulatory authorities, who request a peer review of the groundwater model; and
- Provide recommendations.

1.2 Model Review Scope of Work

The scope of work, as discussed during a meeting with Adani and GHD on 5 September 2013, required the review of the groundwater modelling considering:

- The modelling guidelines (National Water Commission 2012);
- Review of supporting documents and reports; and
- Provide recommendations that would enhance the final model in terms of level of confidence.

Background Information

During the model review study URS reviewed the following documentation:

- GHD, 2012. Adani Mining Pty Ltd Report for Carmichael Coal Mine and Rail Project: Mine Technical Report Hydrogeology Report 25215-D-RP-0026, dated 15 November 2012
- GHD, 2013. Carmichael Coal Project Groundwater Modelling Progress Meeting minutes, dated 7 June 2013, including model recalibration results
- GHD, 2013. Carmichael Coal Mine and Rail Project SEIS Report for Mine Hydrogeology Report, dated 26 July 2013

The initial review provided some background information but as the model was rebuilt to include revised geology and revised underground and open cut mine plans. This meant that the model had to be recalibrated and revised results were generated required a reassessment of the model.

It is noted that URS are not aware of the GHD scope of work nor have URS reviewed any addition Carmichael SEIS submission reports.

2.1 Approach

URS conducted their independent model review based on the consideration of both the Murray Darling Basin Commission Groundwater Flow Modelling Guideline (Aquaterra, 2001) and the more recently published Australian Groundwater Modelling Guidelines (NWC, 2012). The Murray-Darling Basin Commission (MDBC) Groundwater Flow Modelling Guideline is mostly a generic guide, with no specific guidelines on special applications such as coal mine modelling. The new National Guidelines build on the 2001 MDBC guide.

Although these guidelines have no specific guidelines on coal mine modelling they do provide a series of modelling components to be considered, which include:

- Model Conceptualisation;
- Model Design;
- Model Construction;
- Model Calibration; and
- Performance (predictions).

Each of these aspects were assessed in addition to the running and evaluation of the model files.

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Model assessment

As documented in the scope of works, the GHD model revision report (26 July 2013) and supporting documents have been reviewed. Comments regarding the model report have been included which may facilitate in providing clarity.

3.1 General Reporting

In general the report complies with the model components included in the model guidelines, covering all of the recommended headings. In particular, the project scope and objectives are clearly stated and the results are in line with the stated objectives.

The main elements of general reporting are listed and assessed in Table 3-1.

Table 3-1 Assessment of reporting

Item	Assessment criteria	Addressed?	Comments	Impact on Project?
1	Are the model objectives and model confidence level classification clearly stated?	Section 1.2 discusses the purposes of the report Model complexity classification not discussed	Model is considered as Class 2 (medium confidence) according to 2012 Guidelines	None – possibly add comment regarding suitability of model for purpose, which is predicting impacts and developing management policies
2	Are the objectives satisfied?	Adequate		None
3	Is the conceptual model consistent with objectives and confidence level classification?	Maybe	Limited explanation of conceptualisation thus limited support to model	Yes – limits confidence in model if the conceptualisation is unclear or not discussed
4	Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	Limited discussion of conceptualisation, all data presented is discussed	Review undertaken by experienced hydrogeologist	
5	Does the model design conform to best practice?	Yes	MODFLOW-SURFACT model suitable for project	
6	Is the level of model complexity clear or acknowledged?	Not discussed	Model class not discussed	See Item 1
7	Is the model calibration satisfactory?	Refer to Section 4.4		
8	Are the calibrated parameter values and estimated fluxes plausible?	Field and calibrated parameters presented	Only steady-state presented Rewan results considered	Maybe – questions arise regarding model parameters compared to field data. Need to consider sensitivity analysis to back up values used in the model
9	Is a water or mass balance reported?	Section 5.5.5 provides steady-state balance Section 5.7.3 provides post closure balance	Balance inputs and outputs correspond with GHD conceptualisation that groundwater discharges to Carmichael River	
10	Do the model predictions conform to best practice?	Maybe	Refer to Section 4 of this report	

3 Model assessment

Item	Assessment criteria	Addressed?	Comments	Impact on Project?
11	Is the model fit for purpose?	Yes	Assist with monitoring network, water ingress for mine water management	

While the report is generally adequate and covers the majority of model components included in the guidelines, there are a number of areas in which the report could be improved, these include:

- Graphics – Figures
  - Figure 3 is a regional cross-section showing general trends, need to consider pinch-out of units to the west, also Colinlea Sandstone / Bandanna Formation and early Permian (Joe Joe Formation and Drummond Basement) to match Figure 4
  - No conceptual cross-section pre-mining , operation, and/or post-mining
  - No mine plan figure with schedule
  - Add surface water catchment boundaries to Figure 6
  - Figure 7 is very poor quality, possibly use Figure 8 geology?
  - Figure 12 is not clear regarding GAB boundaries
  - Groundwater contour figures could include additional level numbers, flow arrows (Figures 14 to 20)

  Consider using a figure showing the measured water levels and modelled results, this spatial dataset will allow for easier evaluation of anomalous data and location, in addition the steady-state gradients can be compared to the modelled gradients (upward or downward potential)
- Organisation
  - Missing discussion on model complexity, groundwater divide, flow patterns (outside of the mine lease), discharge, and discussion of model assumptions and limitations
  - Section headings missing and / or numbering incorrect (URS acknowledges that it reviewed a draft report so these format issues may already have been addressed)

These omissions or suggestions are not likely to impact significantly on the groundwater model predictions but will allow for more confidence in the model.

3.2 Data Analysis

The model report indicates that a marked amount of site specific data has been collected by GHD and the report provides a summary of the field and laboratory analysis undertaken. Data analysis of slug tests and pumping tests are included as appendices E (slug tests) and F (pumping tests).

It is noted that no validation of the field data was conducted during the model review.

The main elements of data analysis for model development are listed and assessed in Table 3-2 below.

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Table 3-2 Assessment of data analysis

Item	Assessment criteria	Addressed?	Comments	Impact on Project?
1	Has hydrogeology data been collected and analysed?	Yes	Good summary of regional data and results from investigations; could have been more discussion on field K measurements and how they might guide model parameterisation	Minimal impact
2	Are groundwater contours or flow directions presented?	Yes	Contours derived from monitoring points within each aquifer / unit No regional data included	Discussion of groundwater flow patterns outside of the mine lease and the conceptualisation of why flow patterns are contrary to strata will add to the model confidence
3	Have all potential recharge data been collected and analysed?	Yes	Rainfall recharge has been considered for unconfined units conducted using PERFECT Chloride method, and hydrographs considered	Recharge across site and different units not clear – recharge in model different to text. Recharge during sensitivity indicates possible impacts on final void inflow
4	Have all potential discharge data been collected and analysed?	Maybe	No flow observations presented Loss to rivers – and 1 m root depth EVT for shallow groundwater removal from model	No explanation of groundwater level data lows north of Carmichael River and assumed discharge to Carmichael River Conceptualisation discussion required to increase model confidence
5	Have the recharge and discharge datasets been analysed for their groundwater response?	Yes	Hydrographs considered during the study. Hydrographs for available bores are shown in Appendix C.	
6	Are groundwater hydrographs used for calibration?	Yes	Steady-state only	

Assessment of the field data are assessed further in the following sub-sections.

3.2.1 Background data

It is noted that significant site specific geological data was assessed and included in the geological conceptualisation. No regional or Galilee Basin hydrogeological reports or data was considered, based on the references included in Section 2.2 of the report.

It is considered that the conceptualisation of groundwater flow and recharge / discharge could be improved. It is suggested that the following hydrogeological reports be considered when revising the report:

- URS (2012), Report for Hancock Coal Pty Ltd Groundwater Modelling Report – Alpha Coal Project, report ref 42626880, dated 28 March 2012 (Alpha SEIS submission);
- URS (2012b), Report for Hancock Galilee Pty Ltd Kevin's Corner SEIS Groundwater Report, report ref 42626920, dated 18 May 2012;
- Heritage Computing Report (2013), Galilee Coal Project Groundwater Assessment for Waratah Coal Pty Limited, March 2013;
- RPS Aquaterra (2012), South Galilee Coal Project (SGCP) Groundwater Assessment and Modelling, October 2012;
- RPS Australia East Pty Ltd (2012), Galilee Basin Report on the Hydrogeological Investigations, (www.gbof.com.au); and
- Smerdon, BD and Ransley, TR (Editors) (2012), Water resource assessment for the Central Eromanga region. A report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment, CSIRO Water for a Healthy Country Flagship, Australia.

3.2.2 Aquifer tests

Test pumping was carried out at 3 bore locations to estimate bulk aquifer properties of the AB seam and the D seam. Constant rate tests were conducted to determine aquifer characteristics.

There is no guideline or standard that dictates the exact number of tests that are required to determine the hydrogeological conditions at a site. Rather it is a matter of professional judgement, and would vary from site to site based on the geological complexity, project scope and modelling approach. The number and types of tests carried out at the Carmichael Coal Project site are considered limited as they only consider the coal seams and do not consider all the units that will affected by mining.

Test pumping data were analysed using numerous analytical solutions, such as Hantush (in the AQTESOLV software), and include for confined and leaky aquifer solutions (dependent on the observation bore). The analysis approach is considered appropriate for this study and the results and interpretation are reasonable.

3.2.3 Slug tests

Variable head (slug) tests were carried out on 22 bores and packer testing was conducted at eight locations to provide estimates of the hydraulic conductivity of the alluvium, Tertiary sediments, coal seams, inter- and over-burden, Rewan Formation and Dunda beds.

Data analysis was carried out using the Bouwer-Rice analytical solution using AQTESOLV software. Packer testing was carried out using either single packer or straddle packer tests or interpreted using methods described in 'Routine Interpretation of the Lugeon Water-Test' (Houlsby, 1976).

The Bower and Rice method, which is appropriate for fully or partially penetrating wells, can be used in confined and unconfined conditions. The analysis approach is considered appropriate for this study and the results and interpretation are reasonable.

3.2.4 Field hydraulic parameters

The field results indicate a wide range of data from each of the units tested. A variation in estimates derived from test pumping, packer tests, and slug testing is recognised and reflects the scale dependent nature of permeability testing (especially in fractured or dual porosity aquifers), and also

3 Model assessment

the inherent bias of each particular testing method (test pumping is not possible in formations of very low permeability, for instance).

These results highlight the difficulty in estimating hydraulic parameters at a regional scale in order to provide a reliable estimate of groundwater inflows at the mine scale.

It is noted that the hydraulic conductivity values for the Rewan Group ranged over 4 orders of magnitude, 9.5×10^{-5} to 2.9×10^{-1} m/day. This indicates the variation in permeability in the shallow weathered outcrop and the pristine Rewan Group sediments at depth. The calibrated hydraulic conductivity for model layers representing the Rewan Group was 7.4×10^{-5} m/day, which is slightly below the minimum estimated site value of 9.5×10^{-5} m/day. Sensitivity analysis of this parameter in the model is to be detailed in the report.

In summary testing appears to have been carried out in a competent manner and the data analysis is sound. As a general comment, the field data could have been better integrated into the conceptual model to determine a set of preferred values and ranges for aquifer characteristics such as permeability and storage.

Model Evaluation

In order to evaluate the model URS included a series of checklists, for each of the model process components, which allowed for the consideration and assessment of the model.

4.1 Planning

Table 4-1 Planning phase checklist

Review questions	*Yes/No*	*Comment*
Are the project objectives stated?	Maybe	No objectives listed, however, Section 1.2 discusses report purpose
Are the model objectives stated?	Maybe	Section 1.3 includes scope, which indicates numerical model to be developed and the identification of potential impacts.
Is it clear how the model will contribute to meeting the project objectives?	Yes	Section 5.6.1 provides comments on the model as a predictive tool
Is a groundwater model the best option to address the project and model objectives?	Yes	Complex multilayered geology and groundwater units requires modelling to assess potential impacts of mine dewatering on groundwater resources
Is the target model confidence-level classification stated and justified?	No	No model class or level of confidence required is discussed
Are the planned limitations and exclusions of the model stated?	No	No model limitations are discussed

It is suggested that assumptions and limitations of the model be included to allow for further understanding of modelling and that these limitations are considered in the proposed management, monitoring, and mitigation measures.

4.2 Conceptualisation

Section 5.1 provides a list of the conceptual model components, which include:

- Geology;
- Groundwater Quality;
- Recharge and discharge processes;
- Groundwater levels and flow directions;
- Aquifer hydraulic parameters; and
- Groundwater use

4.2.1 Geology

The report includes detailed description of the mine lease geology, which is included in the 12 layer groundwater model. The geological cross-section indicates uniformly dipping units to the west. It is noted that the groundwater flow patterns across the site are contrary to the dip of these units.

It is considered that higher potentiometric pressures to the north and south are required to facilitate groundwater flow in the directions identified in the report. Are these related to enhanced recharge, folds or structures? No comments regarding geological structures (folding, anticline / synclines) or enhanced recharge within the units to the west is detailed or conceptualised.

It is suggested that comments regarding the potential for interaction or hydraulic connection between the Permian target coal and the GAB units be added. Are there faults that could connect the Clematis Sandstone to the Permian units thus impacting on the GAB?

4.2.2 Groundwater Quality

This is not discussed under Section 5.1 Conceptual Model; however, Section 4.4 provides detailed description of the groundwater chemistry.

4.2.3 Recharge

This is not discussed under Section 5.1 Conceptual Model; however, Section 4.8 provides detailed discussion of GAB recharge mechanisms and recharge rate estimates for the different geological units within the mine area.

It is considered that the recharge (mechanisms and rates) to the Galilee Basin confined Permian units is not well detailed and Section 4.8.5 is incomplete (URS acknowledges it is reviewing a draft report). Additional details are required for the confined aquifers in terms of how recharge is achieved and what rates were included in and across the model domain.

Section 5.3.2 includes comments on recharge which included rates of 0 to 44 mm/yr, which seems to be related to the surficial geology. Modelling used rates of 0.1 to 5 mm/year. Additional clarification is suggested to differentiate and motivate for the recharge used (i.e. recharge calculated during model calibration).

4.2.4 Discharge

Groundwater discharge to the Carmichael River and evapotranspiration (riparian zone) is discussed within Section 5.

4.2.5 Groundwater levels and flow patterns

Groundwater levels in the various units across the mine lease have been contoured and indicate complex flow patterns. The report indicates that the regional water table flow field forms a subdued replica of land surface elevations, with flow typically from the south-west to the north-east. Localised flow directions appear to vary, with a notable south eastward flow direction in the north-west of the lease area. This latter flow direction appears to be related to the local land surface topography and surface drainage, particularly drainage towards the Carmichael River. Groundwater flow north and south of Carmichael River is presented in the report.

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(s), and groundwater low points north of the Carmichael River, would allow for more clarity.

It is noted that the 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.

4.2.6 Aquifer hydraulic parameters

Aquifer hydraulic testing allowed for the compilation of site-specific aquifer parameters. Section 4.6 provides details of the aquifer parameters. Site specific data is discussed in Section 3.2 of this report.

It is suggested that in the conceptualisation an assessment of the groundwater system (dynamic or static) be included based on groundwater gradients, hydraulic conductivity data, and resultant Darcy velocity.

Rewan Group

It is considered that the Rewan Group (comprising layers of sandstone, mudstone and conglomerate) is the basal aquitard for the GAB. Aquifer tests indicate high variability within this unit, indicating interbeds of sandier lithology within the claystone and mudstone of this unit on site. It is noted (Figure 33) that the calibrated hydraulic conductivity for the Rewan Group (7.4×10^{-5} m/day) is slightly lower than the minimum estimated site value of $9.5\ \times10^{-5}$ m/day. It is considered that, as this unit is important in model predictions on the GAB, additional discussion on the sensitivity (Section 5.8.3) results be provided.

4.2.7 Groundwater use

An assessment of registered bores within a 10 km radius of EPC1690 was conducted, allowing for an assessment of use (primarily stock watering). Registered bores within the mine lease were assessed but no site data could be collected.

An estimate of groundwater use, 152 m^3/day, was included in the modelling.

Table 4-2 provides an assessment of the model conceptualisation according to recognised modelling guidelines.

Table 4-2 Conceptual Model checklist

Review questions	*Yes/No*	*Comment*
Has a literature review been completed, including examination of prior investigations?	Yes	Limited use of currently available EIS models considered, only Alpha EIS. No review of regional geology discussed
Is the aquifer system adequately described?	Maybe	Detailed geology and hydrogeology above the target D seam coal, limited consideration of Colinlea Sandstone units, i.e. sub-D units
• hydrostratigraphy including aquifer type (porous, fractured rock ...)	Yes	Confined and unconfined aquifer descriptions included
• lateral extent, boundaries and significant internal features such as faults and regional folds	Maybe	No discussion of structural geology but geology cross-section shows uniformly dipping beds to the west with no recognised structural complexity
• aquifer geometry including layer elevations and thicknesses	Maybe	Geology based on Xenith geological model, but no discussion of assumptions or source of data outside the mine lease.
• confined or unconfined flow and the variation of these conditions in space and time?	Maybe	Groundwater level data for confined and unconfined used. Not clear which levels represent unconfined (variable levels in dataset)
Have data on groundwater stresses been collected and analysed?	No	C027 (p.444) - Alluvium (223m to 227m), something happened after 30/3/2012, kept declining to April 2013. Any explanations?

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Review questions	Yes/No	Comment
		Only steady-state considered
• recharge from rainfall, irrigation, floods, lakes	Yes	
• river or lake stage heights	Yes	Gaining and losing river considered based on available data
• groundwater usage (pumping, returns, etc.)	Yes	Current extraction, 152 m3/day, included in model
• evapotranspiration	Yes	Root depth of 1 m included for discharge in model (EVT)
Have groundwater level observations been collected and analysed?	Yes	Groundwater data from DERM and Adani were analysed. Hydrographs for available bores are shown in Appendix C.
• selection of representative bore hydrographs	Yes	Available hydrographs presented in Appendix C.
• comparison of hydrographs	Yes	Comparing hydrographs at the same locations
• effect of stresses on hydrographs	Maybe	Rainfall has impacts on alluvium and some tertiary bores. However, additional stresses may be imposed to the system but not explained or analysed in the report. For instance, alluvium hydrograph at C027 continues declining from 207 m to 203 m during March 2012 to April 2013.
• water table maps/piezometeric surfaces?	Yes	Maps of average water levels are presented for different hydrogeologic units
If relevant, are density and barometric effects taken into account in the interpretation of groundwater head and flow data?	N/A	
Have flow observations been collected and analysed?	Yes	Flow data for Station No. 333301 and Station No. 333302 were analysed.
• baseflow in rivers	Yes	gaining stream (base flow) in upstream of mining area, losing stream in mining area for the dry season;
• discharge in springs	No	No flow observations presented
• location of diffuse discharge areas?	Maybe	Loss to rivers – and 1 m root depth EVT for shallow groundwater removal from model
Is the measurement error or data uncertainty reported?	Maybe	Not clearly stated
• measurement error for directly measured quantities (e.g. piezometeric level, concentration, flows)	No	Not reported
• spatial variability/heterogeneity of parameters	Yes	Different types of field tests and their locations
• interpolation algorithm(s) and uncertainty of gridded data?	No	Not stated
Have consistent data units and geometric datum been used?	Yes	Consistent system used
Is there a clear description of the conceptual model?	Maybe	Section 5.2 (note comments in Section 3.3 of this report)
Is there a graphical representation of the conceptual model?	Maybe	Geological cross-sectional view provided but no groundwater data (levels, recharge, parameters, etc.)
Is the conceptual model based on all available, relevant data?	Maybe	Consider comments above
Is the conceptual model consistent with the model objectives and target model confidence level classification?	Maybe	No objectives or confidence levels discussed
Are the relevant processes identified?	Maybe	See comments above
Is justification provided for omission or simplification of	Maybe	Section 5.6 includes comments on the

4 Model Evaluation

Review questions	Yes/No	Comment
processes?		conservative approach adopted which included simplifications
Have alternative conceptual models been investigated?	No	No discussion

On page 61, it states *"One possible explanation for the observations is that dry season flows in the Carmichael River are supported primarily by discharges from the Doongmabulla Springs and potentially by direct groundwater discharge to the river upstream of the Mine Area but that direct groundwater discharge to the river itself on and in the near vicinity of the Mine Area is negligible."*

Based on this conceptualisation, baseflow nearby the Doongmabulla Springs should be very close to the maximum base flow in the stream. However, in Figure 39 (Pg.119) it shows that simulated average baseflow in pre-development near the Doongmabulla Springs to be around 1,200 m^3/day, and the maximum base flow of 4,500 m^3/day occurs 3 km downstream of the Springs. Please explain the differences and how the simulated baseflow relates to Figure 23 (Pg. 62).

It is noted that GHD provided the following comment:

Whilst this paragraph could be re-worded to improve its clarity it is not considered to be inconsistent with the modelled flow accretion profile. The pre development modelled accretion profile (Figure 33) shows baseflow gradually increasing from close to zero at the upstream boundary of the Doongmabulla Springs to around 1500 m^3/d at the downstream boundary and continues to increase to around 4500 m^3/d around 3km downstream of the springs (a location which is still around 6-7 km upstream of the Mine Area). This part of the modelled profile is therefore considered to be consistent with the text on page 61 which suggests that "*dry season flows in the Carmichael River are supported primarily by discharges from the Doongmabulla Springs* ***and*** *by direct groundwater discharge to the river upstream of the mine*". We have removed "potentially" and added the bold to improve the clarity. From this point 6-7 km upstream of the Mine Area modelled flows gradually recede to around 4200 m^3/d at the upstream boundary of the Mine Area to 3100 m^3/d at the downstream boundary i.e. as stated in the text "*direct groundwater discharge to the river itself on and in the near vicinity of the Mine Area is negligible".* Furthermore modelled baseflow losses across the Mine Area are comparable to observed losses over the same reach.

4.3 Model Design and Construction

A review of the model software, design and model domain (cells and layers) was conducted. Table 4-3 presents the assessment.

Table 4-3 Model Construction checklist

Review questions	*Yes/No*	*Comment*
Is the design consistent with the conceptual model?	Yes	Section 5.4
Is the choice of numerical method and software appropriate?	Yes	It can handle saturated and unsaturated flow
Are the numerical and discretisation methods appropriate?	Yes	Finite difference scheme
Is the software reputable?	Yes	MODFLOW-SURFACT was used
Is the software included in the archive or are references to the software provided?	Yes	Reference to HGL, 1996
Are the spatial domain and discretisation appropriate?	Maybe	The minimum grid size is 50 m by 50 m, and the maximum grid size is 1000 m by 1000 m. The aspect ratio (20) is considered higher than the MDBC guideline of 10.
• 1D/2D/3D	Yes	3D groundwater model
• lateral extent	Yes	Regional extent was used
• layer geometry?	Yes	Section 5.2
Is the horizontal discretisation appropriate for the objectives, problem setting, conceptual model and target confidence level classification?	Yes	The minimum grid size of 50 m by 50 m is sufficient for the perceived objectives.
Is the vertical discretisation appropriate? Are aquitards divided in multiple layers to model time lags of propagation of responses in the vertical direction?	Yes	Rewan Formation divided to two layers
Are the temporal domain and discretisation appropriate?	Yes	Appropriate assuming annual stress periods, not clear as no mine plan with schedule
• steady state or transient	Yes	Temporal discretisation appropriate
• stress periods	Maybe	Need to verify yearly stress period
• time steps?	Yes	sufficient
Are the boundary conditions plausible and sufficiently unrestrictive?	Maybe	Natural or distant boundaries were used
Is the implementation of boundary conditions consistent with the conceptual model?	Maybe	Limited discussion in the conceptualisation of boundaries
Are the boundary conditions chosen to have a minimal impact on key model outcomes? How is this ascertained?	Maybe	Boundary conditions are considered to have minimum impact Could verify using the modelled water budget, providing the inflow/outflow rates before mining and after mine simulations
Is the calculation of diffuse recharge consistent with model objectives and confidence level?	Maybe	Negative recharge occurred
Are lateral boundaries time-invariant?	Yes	General head boundaries are time-invariant. Are these then constant heads for model simulation? Impact of time-invariant boundary conditions not explained or stated.
Are the initial conditions appropriate?	Yes	Appropriate – steady-state
Are the initial heads based on interpolation or on groundwater modelling?	Yes	Initial conditions from steady-state result

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Review questions	*Yes/No*	*Comment*
Is the effect of initial conditions on key model outcomes assessed?	No	It is noted that the alluvium bores have changing water levels over time, which one was selected and is this representative?
How is the initial concentration of solutes obtained (when relevant)?	N/A	
Is the numerical solution of the model adequate?	No	Numerical solution may not be adequate due to high cumulative percentage discrepancy(8.2% which > 1% typically considered in models)
Solution method/solver	Yes	Adequate – used MODFLOW
Convergence criteria	No	May be too high Typically 1E-3 is this 1E-2 in this model?
Numerical precision	No	Transient simulation with cumulative percentage discrepancy= -8.2% at Stress Period 59 (end of mining)

URS notes GHD comments on the cumulative percentage discrepancy:

It is accepted that the elevated water balance errors in some stress periods of the predictive model represents a genuine shortcoming of the current model. In part this problem is related to the extremely short time period, of around one week after receipt of the final mine plan, which was available to complete the predictive modelling work. It should also be stressed that all numerical models are subject to a degree of numerical error and that the scale of the proposed mine workings, the relatively rapid rate of coal extraction and the complex hydrogeological setting are considered to make this model particularly prone to water balance errors. An initial run of the predictive model was characterised by even higher water balance errors and whilst this was improved it was not possible, in the time available, to reduce the overall level of error to the less than 1% cumulative error target suggested by the groundwater modelling guidelines (National Water Commission, 2012). However, several checks were undertaken, by comparing output from two runs with different water balance errors, which confirmed that neither the reported modelled mine inflow rates or predicted groundwater impacts were sensitive to the modelled water balance error. Further details on the checks undertaken have been prepared for subsequent discussion with the reviewers.

4.4 Calibration and Sensitivity

URS obtained the MODFLOW-SURFACT model files from GHD. The model was run by URS and assessed according to the model guidelines. Table 4-4 presents the review assessment.

Issues requiring consideration were identified during the assessment of the model, these included:

- Test results for hydraulic conductivity vary across 5 orders of magnitude from 3.5 m/day to 5.8×10^{-5} m/day (Section 4.6.1 Pg. 54). Does hydraulic conductivity vary with depth?
- There are several monitoring wells that have continuous measurements for shallow and deep aquifers (Appendix C). Head difference between the aquifers can be observed. The calibration result did not present whether the vertical gradient had been preserved. Where these gradients (up or down) preserved in the calibrated groundwater levels? It is suggested that a figure be added to show spatial spread of modelled values compared to initial measured heads.
- Groundwater head vary by several meters during a year for monitoring wells near rivers. Calibration to an average head for the steady state model did not include effects of storage. Can the steady state model with assumed storage parameters be representative for mining dewatering, especially when dewatering will mainly extract groundwater from storage? Used literature values for storage but no validation through transient calibration has been included.
- How were the surface and groundwater interactions assessed in the steady state model for the dry season particularly outside the mine lease area?
- A total recharge of 2,533 m^3/day is included in the model. The model review indicates 780 m^3/day is rejected from three cells within the model (~ 31% of the total recharge) and the calibrated steady state model water balance (Table 17) indicates a further 1,200 m^3/day is discharged to Other Water Courses.   Please explain how the recharge rate was determined and provide discussion on the effective recharge.
- Calibration to head data can only identify the ratio of recharge to transmissivity, not the recharge rate or transmissivity itself (Haitjema, 1995; 2006). Without further calibration to flow data, the recharge and stream flux may not be identified. Please explain how a robust predictive model can be generated from the current steady state model calibrated to average head data only.
- Head residuals were not presented spatially.
- Hydraulic conductivity (k) distribution was used for Layers 9 to 12 rather than using a uniform k value for a hydrogeologic unit. The k distributions are not displayed. Also, it is noted that a “bull’s eye” (high value in one area) k distribution occurred.

4 Model Evaluation

Table 4-4 Model Calibration checklist

Review questions	Yes/No	Comment
Are all available types of observations used for calibration?	No	Only groundwater head data was used (average only for Alluvium)
Groundwater head data	Yes	Groundwater head data used
Flux observations	No	Not calibrated to flow observation (base flow) or monitoring bore hydrographs
Other: environmental tracers, gradients, age, temperature, concentrations etc.	No	No match to vertical or horizontal gradients was presented. It is suggested that a figure be constructed to show model versus measured across the model domain, for evaluation of flow patterns and gradients
Does the calibration methodology conform to best practice?	Maybe	Only steady-state calibration was conducted. The available hydrographs have more than one year of records, which cover the wet and dry season. No transient calibration was performed.
• Parameterisation	Maybe	Hydraulic conductivity (k) distributions in Layers 9 to 11 have so-called “bull’s eye” (high value at one location). Report considers uniform parameters across the model (homogeneity), model shows heterogeneity, including a one point bull’s eye of high k.
• Objective function	Maybe	Assuming the calibration objective is to minimise the residual error
• Identifiability of parameters	No	Not assessed as relative sensitivity of parameters was not included
Which methodology is used for model calibration?		Section 5.5 discusses automated calibration using PEST and constraints (specified limits)
Is a sensitivity of key model outcomes assessed against?	Maybe	Parameters assessed
• parameters	Yes	Parameters assessed for the steady state calibration
• boundary conditions	No	Not assessed
• initial conditions	No	Not assessed
• stresses	No	Not assessed
Have the calibration results been adequately reported?	Maybe	Only steady-state head calibration reported
Are there graphs showing modelled and observed hydrographs at an appropriate scale?	No	Transient calibration was not conducted
Is it clear whether observed or assumed vertical head gradients have been replicated by the model?	No	Not assessed
Are calibration statistics reported and illustrated in a reasonable manner?	Yes	Calibration statistics reported
Are multiple methods of plotting calibration results used to highlight goodness of fit robustly? Is the model sufficiently calibrated?	Maybe	Only a scatter plot of observed versus simulated performed
• spatially	No	Calibration result not plotted spatially
• temporally	No	Transient calibration not performed
Are the calibrated parameters plausible?	Yes	Calibrated parameters within reasonable ranges, but storage parameters were not calibrated
Are the water volumes and fluxes in the water balance	Maybe	31% of recharge is lost from 3 model cells

Review questions	Yes/No	Comment
realistic?		EVT is very high (7.5% of out flow) but from a limited number of model cells
Has the model been verified?	Maybe	Only verified for the steady-state model even though continuous data is available. Assumed storage parameters not verified

4.5 Predictions

An evaluation of the model in terms of predictions and confidence was conducted. Several comments or questions have been identified, which need to be considered to allow for a better understanding of the modelling. These include:

- The residual saturation assigned for unsaturated zones was 5×10^{-3}. The value is considered low. Please provide discussion on how this value was selected.
- Cumulative percentage discrepancy = -8.2% at Stress Period 59 (last dewatering year); flux percentage discrepancy went up to -42.99% at stress period 35. Based on the Groundwater Modelling Guidelines (SKM, 2012 Pg. 91): "*Mass balance closure error. In numerical models the solutions to the groundwater equations are numerical approximations and, as a result, there is always a small closure error in the mass balance. A cumulative mass balance error of not more than 1% of the total mass balance is considered acceptable. Errors larger than this value point to some inconsistency or error in the model*." Therefore, the predictive model outcome is questioned.
- At the end of Stress Period 59 stream leakage flux was 6,579.615 (m^3/day), and stream gaining flux (base flow) was 6,579.616 (m^3/day). This indicates that stream leakage was balanced by base flow. Same phenomena occurred in the post-closure model. Please explain.
- Horizontal and vertical hydraulic conductivities and storage were not increased for the mined coal seam (the goaf) after mining. It is noted that the mined coal parameters remain the same. Only the vertical hydraulic conductivity was increased for the layers above goaf. The impact of dewatering could be underestimated without including the goaf area. In addition, the impact of multiplying factor for vertical hydraulic conductivity, which is estimated (no actual data available) was not examined using uncertainty analysis.
  Consideration of the change in aquifer parameters, hydraulic conductivity and storage, as a result of longwall mining (goaf) is recommended as these parameters will be higher than the unaltered coal seam, which is currently being simulated in the model post mining.
- The post-closure water balance (Table 22, Pg. 110) requires consideration. The flux into and out of the stream, from groundwater, are exactly the same (Carmichael River Leakage). What's the implication?
- Table 22 indicates the Discharge to Other Water Courses is 651 m^3/day and the error difference is 491 m^3/day, together these account for 45% of recharge (a total of 1,142 m^3/day where recharge is 2,534 m^3/day). These results need to be discussed.
- In Table 27 (Pg. 123), 20% of predicted baseflow impact, 950 m^3/day (Pg. 114), should be less than 200 m^3/day. Information presented in Figure 44 indicates a flow of ~ 400 m^3/day. Please clarify.

Table 4-5 presents the model prediction assessment.

4 Model Evaluation

Table 4-5 Model Prediction checklist

Review questions	Yes/No	Comment
Are the model predictions designed in a manner that meets the model objectives?	Yes	Mining plan was used in the predictive simulation (assuming annual time steps)
Is predictive uncertainty acknowledged and addressed?	Maybe	Only storage parameters were assessed for the predictive simulation. Storage parameters were increased or decreased for all layers at the same time. Only two runs were considered.
Are the assumed climatic stresses appropriate?	Maybe	Long term average climatic stresses were used, but variation was not assessed.
Is a null scenario defined?	Yes	Same extraction rates applied to the prediction period – pumping from existing bores was included
Are the scenarios defined in accordance with the model objectives and confidence level classification?		No model class or level of confidence required is discussed
Are the pumping stresses similar in magnitude to those of the calibrated model? If not, is there reference to the associated reduction in model confidence?	Yes	Same pumping stress applied in the calibration and prediction periods. It is noted that a constant pumping rate (stress) from existing bores was included
Is the temporal scale of the predictions commensurate with the calibrated model? If not, is there reference to the associated reduction in model confidence?	No	Only steady state model was calibrated
Are the assumed stresses and timescale appropriate for the stated objectives?	Yes	Yearly stress period was used / assumed It is noted Section 5.6.2 that the stress period was annual then 5 year then 10 year. Needs clarification that mine plan was divided into annual / equal mining areas.
Do the prediction results meet the stated objectives?	Yes	Predictive inflow, water levels, and baseflow were assessed – assumed objectives
Are the components of the predicted mass balance realistic?	No	Cumulative percentage discrepancy= -8.2% at Stress Period 59 (last dewatering year), and flux percentage discrepancy went up to -42.99% at stress period 35. At the end of Stress Period 59 stream leakage flux was 6,579.615 (m^3/day), and stream gaining flux (base flow) was 6,579.616 (m^3/day). It seems that stream leakage was balanced by base flow.
Are the pumping rates assigned in the input files equal to the modelled pumping rates?	No	At the end of Stress period 59 total modelled pumping rate was 152 (m^3/day) – from model output files; whilst the specified input rate was 201.5 (m^3/day) – from model input files.

4 Model Evaluation

Review questions	*Yes/No*	*Comment*
		It means that mining operations are impacted on the pumping wells, i.e. model cannot deliver the 200 m^3/day at the end of mining.
Does predicted seepage to or from a river exceed measured or expected river flow?	Maybe	The comparison was not performed or stated.
Are there any anomalous boundary fluxes due to superposition of head dependent sinks (e.g. evapotranspiration) on head-dependent boundary cells (Type 1 or 3 boundary conditions)?	Yes	Evapotranspiration occurred only on a few cells (including overlaying with the stream cells, Type 3 boundary). If EVT and stream loss both occurs from these cells then this could result in a double up in discharge from the model. Has this been considered? At Stress period 59 evapotranspiration flux was 3,585 (m^3/day) on these few cells. The flux was more than recharge of 2,533 (m^3/day). This is not sustainable and as the boundaries provide groundwater this casts doubt on the model predictions.
Is diffuse recharge from rainfall smaller than rainfall?	Yes	The modelled recharge should be smaller than the input value because 28% to 31% of recharge was rejected.
Are model storage changes dominated by anomalous head increases in isolated cells that receive recharge?	No	Not occurred
Has particle tracking been considered as an alternative to solute transport modelling?	N/A	

A mine plan with schedule was not provided. For a 5-year plan, were all panels applied from the first year of five years? Or where the panels divided into 5 equal areas and introduced annually during the five years? Please clarify.

4.6 Uncertainty

Uncertainty analyses, allowing for a range of predictions based on the sensitivity analysis was not specifically detailed or discussed in the model report.

It is considered that an uncertainty analysis would provide additional confidence in model predictions with regards to:

- Storage values adopted from literature
- Changes in hydraulic conductivity and storage after longwall mining
- Estimations of groundwater ingress
- Climate change (especially when considering final voids)

Recommendations

Based on the review of the hydrogeological model and report it is considered that several areas in the report are not fully explained or discussed, which could lead to requests for additional information and reduced confidence in the model outputs. It is considered that the following areas of study be discussed in more detail:

- Include a clear description of the conceptual model underpinning the numerical model, additional details to be considered include:
  - Groundwater flow patterns either side of the Carmichael River, specifically the low levels north of the river;
  - Groundwater flow contrary to the dip of the strata
  - Structural geology
  - Recharge mechanisms and rates with regards to the confined Permian units;
  - Groundwater flow rates, movement and discharge in terms of considering the groundwater system dynamic or static. For consideration of drawdown cone extent;
  - Pre- and post-mining conceptual model figures, cross-sections will add value and ease to understanding concepts adopted in model.
- Provide summary of model approach, objectives, and model level. Include statement of assumptions and limitations.
- Validate the location and type of boundaries in the model, emphasising suitability, impact on model results / predictions, and assumptions used when selecting the model boundaries.

5.1 Model Recommendations

Recommendations are made to improve the predictive model performance:

- Calibrate the model with transient head targets and stream flow data, and also preserve vertical head gradients in the model based on the observed head data.
- In the model mass balance, as per the model output file (Table 5-1 below), recharge in the output file is not zero, showing a value of recharge out of the model of 786 m^3/day (~31% of the recharge in).

Table 5-1 Mass Balance Model Output File

IN:		IN:	
---		---	
STORAGE =	0	STORAGE =	0
CONSTANT HEAD =	0	CONSTANT HEAD =	0
FWL STORAGE =	0	FWL STORAGE =	0
FRACTURED WELLS =	0	FRACTURED WELLS =	0
RECHARGE =	2532.7935	RECHARGE =	2532.7935
ET =	0	ET =	0
RIVER LEAKAGE =	0	RIVER LEAKAGE =	0
HEAD DEP BOUNDS =	44680.4375	HEAD DEP BOUNDS =	44680.4375
STREAM LEAKAGE =	6662.3657	STREAM LEAKAGE =	6662.3657
TOTAL IN =	53875.5967	TOTAL IN =	53875.5967

5 Recommendations

OUT:		OUT:	
----		----	
STORAGE =	0	STORAGE =	0
CONSTANT HEAD =	0	CONSTANT HEAD =	0
FWL STORAGE =	0	FWL STORAGE =	0
FRACTURED WELLS =	152.006	FRACTURED WELLS =	152.006
RECHARGE =	786.4142	RECHARGE =	786.4142
ET =	4001.373	ET =	4001.373
RIVER LEAKAGE =	413.8929	RIVER LEAKAGE =	413.8929
HEAD DEP BOUNDS =	41466.4023	HEAD DEP BOUNDS =	41466.4023
STREAM LEAKAGE =	7083.5522	STREAM LEAKAGE =	7083.5522
TOTAL OUT =	53903.6407	TOTAL OUT =	53903.6407
IN - OUT =	-28.0441	IN - OUT =	-28.0441

An explanation is required to discuss this value in the mass balance and the model should be revised to remove negative recharge from mass balance.

- Reduce cumulative percentage error to be under 1%.
- The model flow components, as presented in the report, require clarification. These include:
    - In Table 22 the Carmichael River Leakage in flow is equal to out flow, this indicates that stream leakage was balanced by base flow. This requires an explanation;
    - For evapotranspiration, at model stress period 59 the evapotranspiration flux was 3,585 (m^3/day). This flux is more than recharge of 2,533 (m^3/day). This is not sustainable. This requires validation and clarification of the influence of the model boundaries on the model predictions; and
    - The model input files indicate the modelled pumping rate was 201.5 m^3/day, whilst the model output files indicate a pumping rate of 152 m^3/day. This requires clarification.
- Conduct sensitivity analysis for the transient predictive model based on sensitive parameters.

References

Aquaterra Consulting Pty Ltd, 2000. Murray-Darling Basin Commission Groundwater Flow Modelling Guideline, dated 16 January 2001

National Water Commission, 2012. Australian Groundwater Modelling Guidelines, June 2012.

Limitations

1.1 Geotechnical & Hydro Geological Report

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Adani Mining Pty Ltd.

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The methodology adopted and sources of information used by URS are outlined in this the Report.

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This Report was prepared between [insert date] and [insert date].The information in this Report is considered to be accurate at the date of issue and is in accordance with conditions at the site at the dates sampled. Opinions and recommendations presented herein apply to the site existing at the time of our investigation and cannot necessarily apply to site changes of which URS is not aware and has not had the opportunity to evaluate. This document and the information contained herein should only be regarded as validly representing the site conditions at the time of the investigation unless otherwise explicitly stated in a preceding section of this Report. URS disclaims responsibility for any changes that may have occurred after this time.

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This Report contains information obtained by inspection, sampling, testing or other means of investigation. This information is directly relevant only to the points in the ground where they were obtained at the time of the assessment. The borehole logs indicate the inferred ground conditions only at the specific locations tested. The precision with which conditions are indicated depends largely on the uniformity of conditions and on the frequency and method of sampling as constrained by the project budget limitations. The behaviour of groundwater and some aspects of contaminants in soil and groundwater are complex. Our conclusions are based upon the analytical data presented in this Report and our experience. Future advances in regard to the understanding of chemicals and their behaviour, and changes in regulations affecting their management, could impact on our conclusions and recommendations regarding their potential presence on this site.

Where conditions encountered at the site are subsequently found to differ significantly from those anticipated in this Report, URS must be notified of any such findings and be provided with an opportunity to review the recommendations of this Report.

7 Limitations

Whilst to the best of our knowledge information contained in this Report is accurate at the date of issue, subsurface conditions, including groundwater levels can change in a limited time.

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