# LIDDELL COAL OPERATIONS

APPENDIX **D**

## Liddell Coal Operations
## Groundwater Impact Assessment
## Peer Review (HydroAlgorithmics 2014)

**APPENDICES**

# REVIEW

Our Ref:
HC2014/2

**HydroAlgorithmics Pty Ltd**
**ABN 25 163 284 991**

*PO Box 241, Gerringong NSW 2534*
*Phone (+61 2) 4234 3802*

noel.merrick@hydroalgorithmics.com
www.hydroalgorithmics.com

*Date:* 4 February 2014

*To:* **Ben de Somer**
Environment & Community Superintendent
Liddell Coal Operations Pty Ltd
Glencore
Tel: (02) 6570 9947
Email: ben.desomer@glencore.com.au

*From:* **Dr Noel Merrick**

*Re:* **Liddell Coal Operations - Groundwater Impact Assessment Peer Review**

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## Introduction

This peer review is provided in response to your telephone request of 3 September 2013 and discussions in the Newcastle Glencore office on 30 August 2013. A review has been made of modelling conducted by Sinclair Knight Merz Pty Ltd (SKM) for the Liddell Coal Operations (LCO) open-cut coal mine near Ravensworth in the Upper Hunter Valley. LCO is seeking a Modification to Development Consent DA 305-11-01 for an extension of mining beyond the currently approved extent.

This peer review supersedes the one issued to you on 12 September 2013 and follows from a meeting at the Glencore head office (Sydney) on 13 January 2014.

The initial review was based on the following draft impact assessment report and its Appendix B, a standalone report on a regional groundwater model for the Upper Hunter Valley:

1. SKM, 2013, Liddell Coal Operations Modification 5 to Development Consent DA 305-11-01: Groundwater Impact Assessment. Report prepared for Liddell Coal Operations Pty Ltd. Version V05, April 2013. 84p + 2 Appendices.

2. SKM, 2013, Groundwater Model for the Jerrys and Glennies Water Sources: A Numerical Groundwater Model to Support Xstrata Coal NSW Operations in the Upper Hunter Valley. Report prepared for Xstrata Coal. Version V05, April 2013. Model Version 6.1 Liddell, May 2013. 58p.

Also provided for information was an Issues Log [Document #3, undated] which contained the responses of SKM to review comments and recommendations by Dr Col Mackie of Mackie Environmental Research (MER).

The revised peer review is based on:

4. SKM, 2013, Liddell Coal Operations Modification 5 to Development Consent DA 305-11-01: Groundwater Impact Assessment. Report prepared for Liddell Coal Operations Pty Ltd. Version V08, January 2014. 116p + 3 Appendices.

Document #4 comprises the groundwater impact assessment for the Modification using groundwater model version 7.2. It has the following sections:

1. Introduction
2. Context Setting
3. Groundwater Modelling
4. Groundwater Impacts Assessment
5. Monitoring and Management
6. Conclusions
7. References.

## *Review Methodology*

While there are no standard procedures for peer reviews of entire groundwater assessments, there are two accepted guides to the review of groundwater models: the Murray-Darling Basin Commission (MDBC) Groundwater Flow Modelling Guideline[1], issued in 2001,and the new guidelines issued by the National Water Commission at the end of June 2012 (Barnett *et al.*, 2012[2]). Both guides also offer techniques for reviewing the non-modelling components of a groundwater impact assessment. The 2012 national guidelines build on the 2001 MDBC guide, with substantial consistency in the model conceptualisation, design, construction and calibration principles, and the performance and review criteria, although there are differences in details. The new guide is almost silent on coal mine modelling and offers no direction on best practice methodology for such applications. There is, however, an expectation of more effort in uncertainty analysis, although the guide is not prescriptive as to which methodology should be adopted.

The LCO groundwater impact assessment has been reviewed according to the 2-page Model Appraisal checklist[3] in MDBC (2001). This checklist has questions on (1) The Report; (2) Data Analysis; (3) Conceptualisation; (4) Model Design; (5) Calibration; (6) Verification; (7) Prediction; (8) Sensitivity Analysis; and (9) Uncertainty Analysis. Non-modelling components of the groundwater impact assessment are addressed by the first three sections of the checklist.

The review has also considered compliance with the Director General's Requirements (DGRs) and NSW Office of Water requirements listed in Section 1.2 of Document #4. Particular attention is given to whether the minimal harm considerations of the NSW *Aquifer Interference Policy* (NSW Government, 2012[4]) have been addressed adequately.

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[1] MDBC (2001). Groundwater flow modelling guideline. Murray-Darling Basin Commission. URL: www.mdbc.gov.au/nrm/water_management/groundwater/groundwater_guides

[2] Barnett, B, Townley, L.R., Post, V., Evans, R.E., Hunt, R.J., Peeters, L., Richardson, S., Werner, A.D., Knapton, A. and Boronkay, A. (2012). *Australian Groundwater Modelling Guidelines*. Waterlines report 82, National Water Commission, Canberra.

[3] The new guidelines include a more detailed checklist with yes/no answers but without the graded assessments of the 2001 checklist, which this reviewer regards as more informative for readers.

[4] NSW Government, 2012, NSW Aquifer Interference Policy – NSW Government policy for the licensing and assessment of aquifer interference activities. Office of Water, NSW Department of Primary Industries, September 2012.

It should be recognised that the effort put into the modelling component of a groundwater impact assessment is very dependent on possible timing and budgetary constraints that are generally not known to a reviewer.

A detailed assessment has been made in terms of the peer review checklists in **Table 1** and **Table 2**. Supplementary comments are offered in the following sections.

## *Report Matters*

Document #4 is a good quality document of 116 pages length, plus appendices. It is well structured, well written and the graphics are mostly of high quality. The report includes a 6-page Executive Summary.

The report serves well as a standalone document, with no undue dependence on earlier work.

There should be a regional locality plan as the first figure, rather than a local map. Similarly, there should be a map of classified BSAL. There are several places in the text where Bowmans Creek, not Bowmans Creek alluvium, is described as BSAL.

The report includes water balance summaries for the prediction scenarios but not for the calibrated model.

## *Data Matters*

The attributes of the bores in the monitoring network are now included in Appendix C. There should be a note in the main text to this effect, as the reader is unable to associate groundwater hydrographic responses with formations or depths until this information is discovered too late. The bore naming convention is confusing. At Liddell, the subscript "L" refers to shallow alluvial bores while elsewhere in the model domain "L" refers to deep bores; "S" consistently refers to shallow bores, but near Liddell not as shallow as the "L" bores.

Document #4 provides sufficient detail on the hydrogeological and hydrological characterisation of the site, and some cause-and-effect analysis is presented. However, there are some deficiencies:

- No depth to water map or statistics;
- No reference to "actual ET" in addition to pan evaporation;
- No reference to the residual mass graph in the Climate section, or correlation between groundwater response and rainfall trend within the cause-and-effect analysis;
- No graph of historical dewatering rates;
- BSAL is referenced but mapped extent is not shown;
- In Section 2.6.4, bore LC1 is said to have an invert of 5 mAHD but the hydrograph shows a minimum of about -15 mAHD;
- The observed hydrographs for PGW5_L and Haz3/4 differ substantially from the observed data in Appendix C for the same bores;
- In Section 2.6.6, reference is made to "extensive fracturing above the underground workings to some height"; there should be more explanation of the algorithm and the height adopted for the fractured zone here or later (it is not sufficiently explained anywhere in the report);
- Figure 2-5 is estimated baseflow but in the text it is described as "surface water flow";

- Confidence in the lateral extent of alluvium would be increased if the distribution of logged boreholes were shown (Figure 2-10);
- The dewatering bores M49 and MLB are not marked on a map; they have had meters installed only recently; and
- The key deep bores near Liddell are PGW5 (_S and _L), Haz3/4, Haz6, LC1, Mt Owen 2, 8 South 2, M49; not one appears in the list of bores in Table C-4; does this mean they were not included as calibration targets?

It is noted that a large number of monitoring bores across the broader model extent has been considered and that the groundwater responses are complicated by the net effects of 38 open cut mines and five underground operations.

## *Model Matters*

A good conceptual model graphic is included as Figure 2-20 and there is an adequate description of the key processes acting on the regional groundwater system.

Use of pan evaporation as the maximum evapotranspiration (ET) rate in MODFLOW will overestimate losses through ET if the MODFLOW linear decay function is used. Adoption of Actual ET (as defined by BoM) would be better. No depth to water map is used to indicate whether ET is a likely process.

The model extent (about 21 km x 27 km) is sufficient for inclusion of regional geology and other mines, and the boundaries are sufficiently distant to have no significant edge effects on model results. Subdivision into 20 layers provides more than adequate vertical resolution. As model layers combine coal seams and interburden, modellers must be careful to assign properly weighted average hydraulic conductivities as initial estimates. An alternative approach is to aggregate coal thicknesses over a depth interval and apply a true coal hydraulic conductivity to a coal layer, and a true interburden hydraulic conductivity to an interburden layer.

A Class 2 confidence classification, according to the NWC 2012 guidelines, is appropriate.

Model calibration has been performed using a *monte carlo* approach. While this is a common approach during prediction, where alternative models centred on one calibrated model are explored, its application to calibration is non-standard. The NWC 2012 guidelines do not endorse (or mention) a *monte carlo* approach to calibration. This reviewer does not regard *monte carlo* calibration as an efficient targeted procedure and would much prefer to see a traditional well-accepted systematic approach. Nevertheless, the procedure has found a number of alternative model parameterisations that give acceptable calibration performance statistics. Some use has been made of traditional automated (PEST) procedures to refine estimates of specific yield. The reviewer holds to the opinion that closer matches to the hydrographs in Appendix C could have been achieved with standard procedures.

The model realisations are necessarily constrained to reasonable physical properties but there is no guarantee that they are optimal parameter sets. In all, 12 parameter sets have been retained as acceptable model realisations for predictive purposes.

There should be more explanation of the implementation of the fractured zone in the model. There is no statement on the adopted altitude of the fractured zone but the altitude has been guided by previous referenced studies. There is no clear statement on the final hydraulic conductivities required for calibration except for a location near Liddell where fracturing has been taken (conservatively) to land surface and the vertical hydraulic conductivities are stated.

It should be noted that modelled baseflows have not been reported. They can be used as a second-order calibration target to check that the simulated rates are of a similar magnitude to those derived in the baseflow analysis.

A sensitivity analysis has been done by normalising the adopted parameter range to the (arbitrary) parameter bounds placed on the *monte carlo* simulations. However, this is not an unbiased procedure as the *monte carlo* ranges are not the same for each parameter. The analysis is strictly valid only for specific yield (Sy) where the ranges are generally common. Nevertheless, the procedure does identify parameters that are clearly sensitive and others that are clearly insensitive.

Three scenarios are defined for predictive analysis: base, modification and cumulative. The base case for the Approved mine extent should be clarified with a figure similar to Figure 3-10 for the Modification.

Dewatering assumptions are not clear; is this the reason for South Pit "inflow" prior to start of excavation in 2012 (Figure 3-15)?

The predicted drawdown maps (Figures 3-13, 3-14) in each model layer are sensible. Statements on the drawdown extents would have been informative.

No spatial head distribution maps are included - before, during or after the investigated mining operations. Changes in groundwater flow direction would inform comment on potential water quality changes in the groundwater system.

There is substantial and adequate discussion on groundwater impacts (Section 4). Aquifer Interference Policy minimal harm considerations are addressed except for the estimated percentage increase in the average salinity of water in the nearest stream.

Although the Aquifer Interference Policy has no minimal harm criterion for reduced baseflow or enhanced leakage from a stream, it is necessary to interrogate the model for this impact so that the loss in stream water can be licensed. In Document #4, there seems to be an assumption that this loss is the same as the enhanced leakage from the alluvium to the bedrock. They are not necessarily the same. Fortunately, the surface water and the groundwater belong to a common water source here (Jerrys Water Source), so the correct amount has been calculated. In this case the "take" is the net amount of leakage out of the alluvium following partial replenishment by enhanced leakage from Bowmans Creek. Nevertheless, separate quantification of the stream loss would have allowed comment on whether the impact on stream flow and associated ecosystems might be significant.

Section 4.1.1 says that "Predictive simulations ... further indicate that alluvial groundwater levels will return to current (2013) levels within 50 years...". This has not been demonstrated, and there is no mention elsewhere that a transient recovery run was undertaken.

Cumulative impact findings are clear.

The DGRs and NOW comments in Tables 1-1 and 1-2 are addressed satisfactorily throughout the report.

## **Editorial Matters**

- There are still many typographical and grammatical errors that should be corrected.
- There is often inconsistent spelling of "licences" as "licenses".
- Many references to "Appendix B" are now references to "0".
- Table 3-3 has undefined footnotes.
- Table 3-4 has .0E-6 instead of 5.0E-6 for specific storage.
- Section 3.4, paragraph 1: "...input parameter range determined by the Monte Carlo simulation ..." --> "...input parameter range defined for the Monte Carlo simulation ..."
- Add units to tables of calibration statistics.
- Section 3.8.3, dot point 1: "groundwater levels" --> "water levels" for final void.

## *Conclusion*

This reviewer is of the opinion that "Model Version 7.2 Liddell" is now *fit for purpose*.

Although the *monte carlo* method of calibration is non-standard, sufficient model parameterisations have been identified that give acceptable global calibration performance statistics. The anticipated mine inflow is now constrained by field control at Cumnock during calibration.

The objectives expressed in terms of DGR and NOW requirements have been addressed satisfactorily.

The quantitative estimates of water takes  for licensing purposes are reasonable and the investigation of environmental impacts related to groundwater extraction during mining has been sufficiently thorough.

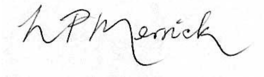
Recommendations made in the initial review have been addressed satisfactorily in the main. Those which have not been addressed are:

1. "Provide a full water balance for the five[5] calibrated models, and comment on variability between the results;

2. Assess the degree of agreement between simulated and estimated  baseflows;

3. Document the way in which underground fractured zones have been or should be modelled."

Yours sincerely,



Dr Noel Merrick

[5] Now 12

Table 1. MODEL APPRAISAL: Liddell Version 7.2 Model Preparation

| Q. | QUESTION | Not Applicable or Unknown | Score 0 | Score 1 | Score 3 | Score 5 | Score | Max. Score (0, 3, 5) | COMMENT |
|---|---|---|---|---|---|---|---|---|---|
| **1.0** | THE REPORT | | | | | | | | |
| 1.1 | Is there a clear statement of project objectives in the modelling report? | | Missing | Deficient | Adequate | Very Good | | | Sections 1.2, 1.3. |
| 1.2 | Is the level of model complexity clear or acknowledged? | | Missing | No | Yes | | | | Reference to new national guidelines. Class 2 confidence classification. Equivalent to Impact Assessment Model, medium complexity. |
| 1.3 | Is a water or mass balance reported? | | Missing | Deficient | Adequate | Very Good | | | Nothing for calibration model. Provided for prediction scenarios. |
| 1.4 | Has the modelling study satisfied project objectives? | | Missing | Deficient | Adequate | Very Good | | | DGRs and NOW requirements are assessed. |
| 1.5 | Are the model results of any practical use? | | | No | Maybe | Yes | | | The findings of minimal impact are plausible. |
| **2.0** | DATA ANALYSIS | | | | | | | | |
| 2.1 | Has hydrogeology data been collected and analysed? | | Missing | Deficient | Adequate | Very Good | | | Some cause & effect analysis; monitoring network details in App.C; good hydrology; no actual ET. |
| 2.2 | Are groundwater contours or flow directions presented? | | Missing | Deficient | Adequate | Very Good | | | No extensive map of observed water level contours but zones of hydraulic gradient (and direction) for alluvium (Fig.2-14) |
| 2.3 | Have all potential recharge data been collected and analysed? (rainfall, streamflow, irrigation, floods, etc.) | | Missing | Deficient | Adequate | Very Good | | | Some comments on flood recharge responses at bores but not in conceptual model. What is the flood extent? How often? |
| 2.4 | Have all potential discharge data been collected and analysed? (abstraction, evapotranspiration, drainage, springflow, etc.) | | Missing | Deficient | Adequate | Very Good | | | State "actual ET" (BoM) - more relevant than evaporation. Appears to be little private groundwater usage - 3 bores. State the typical depth to water to guide need for EVT package. |

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|---|---|---|---|---|---|---|---|---|---|
| 2.5 | Have the recharge and discharge datasets been analysed for their groundwater response? | | Missing | Deficient | Adequate | Very Good | | | Residual mass compared with groundwater hydrographs and baseflow estimates. Figure 2-15 should be related to timing of dewatering events. There is discussion on upwards/downwards flow - statistics on vertical head gradients would be useful. |
| 2.6 | Are groundwater hydrographs used for calibration? | | | No | Maybe | Yes | | | Only shallow hydrographs are used close to Liddell. Deeper regional bores are used. Hydrographs date back to 2001 - long record. State natural fluctuation in water levels for application of AI Policy minimal harm rules. |
| 2.7 | Have consistent data units and standard geometrical datums been used? | | | No | Yes | | | | |
| **3.0** | CONCEPTUALISATION | | | | | | | | |
| 3.1 | Is the conceptual model consistent with project objectives and the required model complexity? | | Unknown | No | Maybe | Yes | | | |
| 3.2 | Is there a clear description of the conceptual model? | | Missing | Deficient | Adequate | Very Good | | | Section 2.6.6 |
| 3.3 | Is there a graphical representation of the modeller's conceptualisation? | | Missing | Deficient | Adequate | Very Good | | | Perspective diagram in Fig.2-20. |
| 3.4 | Is the conceptual model unnecessarily simple or unnecessarily complex? | | | Yes | No | | | | Major processes are included. Stratigraphy is detailed. |
| **4.0** | MODEL DESIGN | | | | | | | | |
| 4.1 | Is the spatial extent of the model appropriate? | | | No | Maybe | Yes | | | Dimensions 21 km x 27 km. Cell size uniform 100m. 20 layers, 205 rows, 274 columns, 677,000 active cells. Expanded from prior MER model. |
| 4.2 | Are the applied boundary conditions plausible and unrestrictive? | | Missing | Deficient | Adequate | Very Good | | | Reasonable no-flow boundaries. Heads at GHB boundaries are not shown or defended, as there is no supplied regional observed groundwater contour map. ET rate is too high (for linear decay function). RCH algorithm is %rain. Predicted drawdown contours for proposed development do not reach boundaries. |
| 4.3 | Is the software appropriate for the objectives of the study? | | | No | Maybe | Yes | | | MODFLOW-SURFACT and Groundwater Vistas. |

Table 2. MODEL APPRAISAL: Liddell Version 7.2 Model Implementation

| Q. | QUESTION | Not Applicable or Unknown | Score 0 | Score 1 | Score 3 | Score 5 | Score | Max. Score (0, 3, 5) | COMMENT |
|---|---|---|---|---|---|---|---|---|---|
| **5.0** | CALIBRATION | | | | | | | | |
| 5.1 | Is there sufficient evidence provided for model calibration? | | Missing | Deficient | Adequate | Very Good | | | Sufficient for performance against groundwater levels, and historical mine inflow. No indication of spatial distribution of residuals except weakest at Swamp Creek (Glendell). Scattergrams and performance statistics are given. |
| 5.2 | Is the model sufficiently calibrated against spatial observations? | | Missing | Deficient | Adequate | Very Good | | | Local calibration is based on 6 shallow bores along a north-south corridor 45 km long. The hydraulic gradient is reasonably replicated along this transect. Regional calibration on many regional shallow and deep bores. There is no simulated contour map of groundwater levels. |
| 5.3 | Is the model sufficiently calibrated against temporal observations? | | Missing | Deficient | Adequate | Very Good | | | Hydrographs for all bores are presented for comparison in App.C. Simulated hydrographs generally have less amplitude than observed. |
| 5.4 | Are calibrated parameter distributions and ranges plausible? | | Missing | No | Maybe | Yes | | | Consistent with previous studies and site tests. |
| 5.5 | Does the calibration statistic satisfy agreed performance criteria? | | Missing | Deficient | Adequate | Very Good | | | Alluvial bores: 3-5%RMS, 1.5-2.3mRMS. Project bedrock bores: 2-3%RMS, 4-5mRMS. All bedrock bores: 8-10%RMS, 14-17mRMS. |
| 5.6 | Are there good reasons for not meeting agreed performance criteria? | N/A | Missing | Deficient | Adequate | Very Good | | | There was a prior agreement to exclude from calibration the deeper bores close to Liddell. |
| **6.0** | VERIFICATION | | | | | | | | |
| 6.1 | Is there sufficient evidence provided for model verification? | N/A | Missing | Deficient | Adequate | Very Good | | | All data used for calibration. |

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| 6.2 | Does the reserved dataset include stresses consistent with the prediction scenarios? | N/A | Unknown | No | Maybe | Yes | | | |
| 6.3 | Are there good reasons for an unsatisfactory verification? | N/A | Missing | Deficient | Adequate | Very Good | | | |
| **7.0** | PREDICTION | | | | | | | | |
| 7.1 | Have multiple scenarios been run for climate variability? | | Missing | Deficient | Adequate | Very Good | | | The assumptions for future rainfall appear to be unstated. It is likely that a single average climate has been used in accordance with standard practice. |
| 7.2 | Have multiple scenarios been run for operational /management alternatives? | | Missing | Deficient | Adequate | Very Good | | | 3 scenarios: base, modification and cumulative. Base case should be clarified with a figure similar to Figure 3-10 for the Modification. Dewatering assumptions are not clear; is this the reason for South Pit "inflow" prior to start of excavation in 2012? Stochastic results and statistics are based on 12 realisations. |
| 7.3 | Is the time horizon for prediction comparable with the length of the calibration / verification period? | | Missing | No | Maybe | Yes | | | The time period for transient calibration is 32 years from 1980 to 2012. Prediction period is 18 years from 2013 to 2030. There is no reported transient recovery simulation. |
| 7.4 | Are the model predictions plausible? | | | No | Maybe | Yes | | | Plausible drawdown magnitudes and drawdown extent.<br>There is no comparison of simulated baseflows with estimated actual baseflows. Table 2-2 has average 3500 ML/a in Bowmans Ck at Liddell. What is simulated rate? |
| **8.0** | SENSITIVITY ANALYSIS | | | | | | | | |
| 8.1 | Is the sensitivity analysis sufficiently intensive for key parameters? | | Missing | Deficient | Adequate | Very Good | | | Investigated during *monte carlo* simulations. Not an unbiased procedure as the adopted parameter range is normalised to arbitrary parameter bounds. Strictly valid only for Sy where ranges are common. |
| 8.2 | Are sensitivity results used to qualify the reliability of model calibration? | | Missing | Deficient | Adequate | Very Good | | | Figures 4-6 to 4-8 [Doc #2]. Adopted parameter ranges are not limited by calibration performance, but only by successful convergence. |

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|---|---|---|---|---|---|---|---|---|---|
| 8.3 | Are sensitivity results used to qualify the accuracy of model prediction? | | Missing | Deficient | Adequate | Very Good | | | Stochastic results and statistics are based on best 12 realisations. |
| **9.0** | UNCERTAINTY ANALYSIS | | | | | | | | |
| 9.1 | If required by the project brief, is uncertainty quantified in any way? | | Missing | No | Maybe | Yes | | | Stochastic results and statistics are based on 12 realisations. This does not guarantee reliable standard deviations, as many more realisations are possible. Although the global statistics appear OK, the different realisations can give simulated hydrographs with wide offsets in absolute magnitudes. |
| | | | | | | | | | |
| | TOTAL SCORE | | | | | | | | PERFORMANCE: |