Review of Maules Creek Coal Project Groundwater Impact Assessment

Prepared for: Maules Creek Community Council and Namoi Water

October 2011

Water Resource Australia

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Executive Summary

A groundwater model in the Maules Creek area of the Namoi Catchment in New South Wales has been developed by Australasian Groundwater and Environmental Consultants Pty Ltd. (AGE) in support of the Environmental Assessment for the Maules Creek Coal Mine (Project). The objective of the groundwater study was to assess the impact of the Project on the hydrogeological regime and to meet the applicable Director-General's Requirements.

This report provides a review of the model development and reporting according to Australian modelling guidelines (MDBC, 2000) and the Project Director-General's Requirements.

Setup and development of the steady state model is in line with current industry practices – as indicated by the MDBC checklist (Table E-1, MDBC, 2000). A thorough background literature research has been conducted and used as the foundation for the conceptual and numeric models.

The modelling report is overall of a high quality and provides sufficient figures and diagrams to provide illustrations of key features and results.

Using the MDBC guidelines checklist, the modelling is found to be deficient and/or lacking in the areas of calibration, verification, sensitivity analyses and uncertainty analyses – each to varying degrees. The deficiency that stands out the most is the incomplete calibration. The steady state calibration is reported to have a good statistical calibration (SRMS); however the report does not provide any other measures by which to judge the validity of the model, chiefly the qualitative assessments required by the MDBC guidelines, if available. These qualitative assessments are often more telling of the reasonableness of a model's ability to replicate the groundwater and surface water systems than the statistics. This project is rich in comparison to most projects for studies and data as indicated by the fact the report dedicates nearly 37 pages to describing it all but only two dedicated to describing how the model matches heads.

The calibration procedure is also found deficient in the respect a transient calibration was not conducted despite the fact this project has a relatively large amount of recent and historic data/studies available to it. The reasoning provided by AGE, that they could not perform a transient calibration because pumping records are not publically available, does not seem to stand up when looked at closely or at least is in need of more explanation. Firstly, Aston Resources is a member of the Namoi Water Study and as such has or could have access to the usage data provided by NOW for that study. Secondly, calibration could have been done based upon assumed usage and qualitative assessment of fit made and thirdly, calibration could have been considered for just the bedrock only. The latter is arguably the most important.

The primary risks of impact being assessed are associated with the alluvial systems yet the connection between the alluvial and bedrock systems in the calibrated model are not assessed to the previous studies and conceptual model to provide the reader with any confidence the model is replicating reality.

Additional recommendations provided by the reviewer regarding the Maules Creek groundwater modelling report are as follows:

- The cumulative impact assessment should consider the declining water levels within the alluvial systems along with the impacts of the surrounding mines as currently presented.
- A clear method for identifying mining related loss of well yields from background yield losses should be defined up front to eliminate any confusion or difficulties after the fact.
- Recommendations by AGE for groundwater monitoring and seepage inflow measurements should be included in the consent requirements if approved.

The overall impression left after the review is that the work done is competent and well presented, however it is the work not done that leaves cause for concern and uncertainty.

1. Introduction

The Maules Creek Coal Mine was approved in 1995 and is seeking a contemporary Project Approval for the construction and operation of an open cut mine. The open cut coal mining is estimated to extract up to 13Million tonnes per annum (Mtpa) over a mine life of 21 years.

The objective of the groundwater assessment is to assess the impact of the Project on the hydrogeological regime and to meet the applicable Director-General's Requirements (DGRs).

This report provides a peer review for Maules Creek Community Council (MCCC) and Namoi Water of the Maules Creek Coal project Groundwater Impact Assessment (Project). The review is to be within the context of industry best practice and meeting the DGRs.

A glossary of technical terms is provided in Appendix A.

2. Background Information

2.1 Scope of Work

The key tasks requested by MCCC/Namoi Water for the review of the groundwater assessment conducted in support of the Project submission were:

- A review of the groundwater assessment report by AGE (AGE, June 2011);
- A summary of AGE findings and how they relate to the DGRs as well as industry best practices, i.e. Murray Darling Basin Commission (MDBC) guidelines for modelling exercises (MDBC, 2000).
- An identification of limitations, if any, of the work conducted/presented and how they relate to fully satisfying the DGR requirements as well what work, analyses, reporting could be done to provide further assessment and confidence in findings, if any.
- Recommendations, if any, for further action/discussion.

2.2 Supplied Information

The application documentation on which this review is based are:

1. Australasian Groundwater and Environmental Consultants, Pty, Ltd. (June 2011), *Maules Creek Coal Project Groundwater Impact Assessment*. Prepared for Aston Resources Limited.
2. Hansen Bailey, (July 2011), *Maules Creek Coal Project Environmental Assessment Statement.* Prepared for Aston Coal 2 Pty Limited

The above references were downloaded from the NSW Government Planning website for major projects (http://majorprojects.planning.nsw.gov.au).

2.3 Review Criteria/Guidelines

The review has been designed to provide an assessment of the groundwater assessment based upon unbiased or subjective criteria. As such the MDBC guidelines process for review has been selected for the review along with the DGRs for the project available on the project planning website (http://majorprojects.planning.nsw.gov.au).

2.3.1 MDBC Guidelines

The 2-page review checklist (Table E-1, Appendix E, MDBC, 2000) provided in the guidelines has been selected for the model review. Not all questions in the checklist are relevant to the review - where possible these have been duly marked.

2.3.2 Director General Requirements

A copy of the DGRs was downloaded from the NSW planning website. The relevant section(s) that pertain to groundwater are summarised below.

- a risk assessment of the potential environmental impacts of the project, identifying key issues for further assessment;
- a detailed assessment of the key issues specified below, and any other significant issues identified in the risk assessment (see above), which includes:
  - A description of the existing environment, using sufficient baseline data;
  - An assessment of potential impacts of the project, including any cumulative impacts, taking into consideration any relevant guidelines, policies, plans and statutory provisions (see below); and
  - A description of the measures that would be implemented to avoid, minimise and if necessary, offset the potential impacts of the project, including detailed contingency plans for managing any significant risk to the environment.
- a statement of commitments, outlining all the proposed environmental management and monitoring measures
- Soil and Water
  - detailed modelling of the potential surface water and groundwater impacts of the project;
  - a detailed site water balance, including a description of the measures to be implemented to minimise water use on site;
  - a detailed assessment of the potential impacts of the project on:
    - the quality and quantity of both surface water and ground water resources;
    - water users, both in the vicinity of and downstream of the project;
    - the riparian and ecological values of the watercourses both on site and downstream of the project; and
    - environmental flows; and
  - a detailed description of the proposed water management system for the project and water monitoring program.

2.4 Review Limitations

The level of effort and detail provided as part of a project submission is heavily dependent upon timing and budgetary constraints - details that are unknown by the reviewer. Hence any item(s) that may be commented as lacking or deficient are not necessarily an indication of unwillingness or inability to perform said task but instead a result of the prioritisation of tasks.

Given the above limitation by the reviewer, the following review has not made any assumptions regarding the cause for deficiencies, if any, but instead focuses upon what is and isn't presented and what are the potential consequences.

3. Peer Review

3.1 MDBC Guidelines

A copy of the completed review checklist is provided in Appendix B. A discussion of findings is provided in the following sections corresponding with the sections of the review table.

3.1.1 The Report

The modelling and assessment report is a standalone document of high quality. Numerous cross-sections and "cartoon" diagrams are used to clearly present conceptualisations and subsurface structural understandings.

"The objective of the groundwater study was to assess the impact of the Project on the hydrogeological regime and to meet the applicable Director Generals Requirements." (AGE, 2011). These two objectives are essentially the same and as such will be commented further in Section 3.2.

3.1.2 Data Analysis

The assessment is founded upon a seemingly thorough literature review and the modelling is where possible based upon previous modelling and site investigations throughout the study area. Documentation of where information has been collected seems quite thorough.

Although the report is quite thorough in its description of different sources of information and previous studies, the report would benefit from a summary section which provides a series of specific summary tables dedicated to what relevant information is available from all the sources. For example, from all the historic and current studies within the study area, provide a summary of the water level information (time, location, aquifer source, and level(s)) available. This would provide the reader a clear understanding of what water level information is available for steady state and transient calibration.

Recharge and discharge rates have not been explicitly estimated as part of this study. Response to rainfall events were presented and commented upon. A cumulative rainfall deficit was provided. Initial recharge rates were assumed based upon previous modelling in the area and then allowed to change in the bedrock areas for calibration.

3.1.3 Conceptualisation

The conceptual model is the most important part of any modelling exercise as it provides the framework and limitations for all analyses and assumptions. The report provides a good summary of the conceptual framework used to construct and constrain the model along with graphs and diagrams where applicable to further demonstrate the ideas.

Overall the conceptual model in combination with the data presentation provides an adequate description of the major hydrogeologic processes.

3.1.4 Model Design

The documentation and design of the model seem reasonable and fit for purpose. One of the key factors in model development is the "[t]he model must not be configured or constrained such that it artificially produces a restricted range of prediction outcomes" (MDBC, 2000). The explicit boundary conditions at the edge of the model seem to be unrestrictive.

It appears that AGE have adopted hydraulic parameters from the more transmissive lower lying areas of the catchment as hydraulic parameters for the smaller tributaries such as Horsearm Creek, Maules Creek, etc. The database and conceptualisation provided within the AGE report and previous studies (Coffeys and UNSW) demonstrate that these catchments have a much lower hydraulic properties, typically orders of magnitude lower. Given that these catchments are of much greater risk for impact than the lower more transmissive aquifers, it would be most prudent and considered best practice to have these aquifers characterised as close to the fields study results as possible. The potential consequence of characterising the aquifer(s) with much higher transmissivities than what is known to exist there is to under estimate the drawdown propagation and thus impacts of the project. Therefore, it is highly unlikely the parameterisation of these tributary aquifers is in any way conservative or a worst case scenario.

AGE note that Evapotranspiration (ET) was applied at a maximum potential ET rate of 0.4mm/day, that this assumed rate is “at the lower end of the range of possible values,” and that any higher rates caused numerical stability problems. While this does raise some red flags for the model it is not uncommon and does not necessarily render a model invalid when ET is a minor component of the overall mass balance. In the case of this model ET comprises over 15% the total budget, and greater than 1/3 rainfall recharge, despite being set at such a small maximum potential rate. This would indicate a large area of the model must have water levels within the recharge extinction depth (2m). This seems unlikely for an alluvial system that has experienced declining water levels up to 3 metres in the last 15years (AGE, 2010). A map of depth to groundwater level should be provided for clarification. It would also be inferred that if ET were such an important component of the groundwater system that potential impacts to GDEs would of concern given they would be the primary source of ET.

The above issue of ET may also be a demonstration that the omission of groundwater abstraction in the calibration of the model is not as insignificant an issue as the authors have claimed. AGE state “*the extraction rate from bores is accounted for in the balance of inputs and outputs adopted during the steady state model calibration. Groundwater discharging from the model via drains, river flow, evapotranspiration and constant head cells account for water that would be removed by irrigation from the aquifer*.” The above statement and assumptions raises many causes for concern or comment:

- A steady state simulation provides an “average” condition or state of a system based upon average rates of inflow and outflow – how is a steady state simulation able to account for abstraction in a long-term average manner when the abstraction is causing declining water levels over the last 15years and as such indicates it exceeds the natural net inflow? Wouldn’t the long-term average simulated condition be less than the current if not dry? How could this match current water levels as is the objective of the steady state?

- The mechanisms described that would account for the omission of abstraction are typically shallow features such as river channels and ET (up to 2m below ground surface). In order for these to then extract water from the model the estimated water level must be within this depth from surface. By definition, the model must have heads greater than existing conditions, or the boundary conditions have much lower draining depths, in order the create the increased flow and existing depth to water level contour./profile.

- In this instance the estimated baseflow rates to the surface water systems must be an over estimate of existing conditions and any comparison in the results of a percent decrease in flow would not be valid or at least would be considered an under estimate of relative change and thus not meet the DGRs.

- This assumption also then assumes a greater connection between the surface water and groundwater systems which can then under estimate impacts in the alluvial groundwater system from drawdown in the bedrock. Greater water levels in the alluvium results numerically in a greater transmissivity, resulting in less drawdown. Greater connection of the River cells with the alluvium results in less drawdown. Greater water levels in the alluvium (from a steady state simulation used as an initial head in the transient simulation) would start the transient simulation with too much water in storage in the alluvium, which are often orders of magnitude greater than that in the bedrock aquifers.

- Given the above notes it is difficult to ascertain how this assumption could lead to a conservative or worst case simulation of potential impacts. In addition, by not including groundwater abstraction, and the current decline of water levels, the modelling is not considering all cumulative impacts as required by the DGRs.

3.1.5 Calibration

Calibration has been limited to steady state only. “Steady state simulations...are used to model equilibrium conditions (e.g. representing the long term “average” hydrological balance), and/or conditions where aquifer storage changes are not significant” and [t]ransient simulations are used to model time-dependent problems, and/or where significant volumes of water are released from or taken into aquifer storage” (MDBC, 2000). As such, the model is calibrated for long term average conditions, however it is being used to assess transient time and storage dependent problems - this is not an ideal situation.

The calibration procedure is found to be deficient in the respect a transient calibration was not conducted despite the fact this project has a relatively large amount of recent and historic data/studies available to it. The reasoning provided by AGE, that they could not perform a transient calibration because pumping records are not publically available, does not seem to stand up when looked at closely or at least is in need of more explanation. Firstly, Aston Resources is a member of the Namoi Water Study and as such has or could have access to the usage data provided by NOW for that study. Secondly, calibration could have been done based upon assumed usage and qualitative assessment of fit made and thirdly, calibration could have been considered for just the bedrock only. The latter is arguably the most important.

The level of confidence in transient calibration would be limited because of the unknown/uncalibrated flow rates (pit inflows and potentially inconsistent usage data), however this is still present for the steady state simulation as the natural flow rate to the river and creek systems is not known either. In the end even a qualitative assessment provides a level of reasonableness above not doing anything.

The MDBC guidelines provide a table of model calibration performance measures (Table 3.2.1, MDBC, 2000). The steady state calibration conducted is compared and summarised using this table as its basis.

Table 3-1 Calibration Performance Measures

Performance Measure[1)]	*Criterion[1)]*	*Comment(s)[2)]*
Water balance Difference between total inflow and total outflow, including changes in storage, divided by total inflow or outflow, expressed as a percentage.	Less than 1% for each stress period and cumulatively for the entire simulation.	A water balance is provided for review with an error of <1%.
Iteration residual error The calculated error term is the maximum change in heads (for any node) between successive iterations of the model.	Iteration convergence criterion should be one to two orders of magnitude smaller than the level of accuracy desired in the model head results. Commonly set in the order of millimetres or centimetres.	Iteration convergence criteria is not documented.
Qualitative measures Patterns of groundwater flow (based on modelled contour plans of aquifer heads). Patterns of aquifer response to variations in hydrological stresses (hydrographs). Distributions of model aquifer properties adopted to achieve calibration.	Subjective assessment of the goodness of fit between modelled and measured groundwater level contour plans and hydrographs of bore water levels and surface flows. Justification for adopted model aquifer properties in relation to measured ranges of values and associated non-uniqueness issues.	A general review and discussion on goodness of fit is presented. A graph of predicted vs. observed heads is also provided. No obvious bias is present. No justification for surface flows is provided. Justification for adopted model parameters is provided to measured ranges. Non-uniqueness is not explicitly addressed in calibration.
Quantitative measures Statistical measures of the differences between modelled and measured head data. Mathematical and graphical comparisons between measured and simulated aquifer heads, and system flow components.	Residual head statistics criteria are detailed in Section 3.3. Consistency between modelled head values (in contour plans and scatter plots) and spot measurements from monitoring bores. Comparison of simulated and measured components of the water budget, notably surface water flows, groundwater abstractions and evapotranspiration estimates.	RMS error and Scaled RMS are provided for a selected set of the original data set. No comparison of flows either conceptual or measured is presented. Justification for the rate of average baseflow to the ephemeral streams is not provided.

Notes: 1) MDBC, 2000
2) Reviewer's comments

The calibration conducted would at best have to be considered basic according to MDBC guidelines. The approach adopted by the modellers would seem to be more in line with the following description provided within the guidelines:

"where understanding or data are lacking, it is possible to design the associated model aspects to be conservative with respect to their intended use (eg. assuming an unknown aquifer parameter or stress is at the upper or lower limit of a realistic range)."

However the above philosophy is not an exemption from following standard calibration and sensitivity procedures to describe, assess and quantify non-uniqueness within the model. Non-uniqueness is the situation whereby many model input values and arrangements can produce the same or equally acceptable solutions. This situation arises because of the numerous variables available within the model setup. The recommended procedure for addressing non-uniqueness is described within the MDBC guidelines as follows:

> *The main methods that should be employed in conjunction to reduce the non-uniqueness problem comprise:*
>
> - *calibrating the model using hydraulic conductivity (and other) parameters that are consistent with measured values; and,*
> - *calibrating to multiple distinct hydrological conditions with that parameter set.*
>
> *The first method is designed to restrict the possible range of parameters to values that are consistent with the actual ("unique") values of the aquifer. The second method provides an indication of the predictive performance of a model by demonstrating that a given set of input model parameters (consistent with field measurements) are capable of reproducing system behaviour through a range of distinct hydrological conditions. The variation in hydrological conditions should not just relate to natural conditions, but also to induced stresses (e.g. pumping, river regulation, etc.).*
>
> *Similarly to the first method, a suggested third method of reducing the non-uniqueness problem involves the use of measured groundwater flow rates (eg. stream baseflow) as calibration targets, as this restricts the water budget to values that are consistent with actual aquifer conditions. However, it is often not practical or possible to directly measure groundwater flow rates, and where it is possible to estimate them, there is usually a large degree of uncertainty associated with the estimates, so this method is often not applicable.*
>
> *It is highly preferable that a model is calibrated to a range of distinct hydrological conditions (eg. prolonged or short term dry or wet periods, and ranges of induced stresses), and that calibration is achieved with hydraulic conductivity and other parameters that are consistent with measured values, as this helps address the non-uniqueness problem of model calibration.*

The model calibration presented in the report only addresses the first of three methods to be used conjunctively to address non-uniqueness. Simply put the model as reported is a non-unique solution with no evaluation as to the limits of possible solutions and the likely impact on this would have on predictive results.

3.1.6 Verification

"Verification (also called validation) is a test of whether the model can be used as a predictive tool, by demonstrating that the calibrated model is an adequate representation of the physical system. The common test for verification is to run the calibrated model in predictive mode to check whether the prediction reasonably matches the observations of a reserved data set, deliberately excluded from consideration during calibration" (MDBC, 2000).

Verification was not performed and/or presented in the model report. The aim of the verification/calibration being to replicate the rate of drawdown associated with mining.

It is noted in the predictive simulation setup description that the predictive model is intended to be simulating impacts/water levels from the commencement of mining in 2006 – yet a comparison of the predictive results for the first 5 years of mining with the monitoring dataset has not been provided. This period would at face value seem to be a reasonable datasets from which either a transient calibration or verification exercise could have been performed as there would be some monitoring data as required by the consent requirements for Boggabri Coal.

3.1.7 Prediction

The setup of the predictive simulations is typical for an open pit mining and reclamation plan.

The assumed parameterisation of the backfill is reasonable.

The presentation of results within the bedrock aquifers is adequate to understand predicted impacts.

Predictive model results that describe flow rates and/or changes to flow rates should have a caveat with them stating the model is not calibrated to any flow rates. This is not to say the reported values are wrong or even unreasonable – it just that is has not been demonstrated that the model provides reasonable estimates of flow rates. In addition, it is not demonstrated that any estimates of flows to and from the alluvium or changes in them are considered worst case or conservative despite the claims otherwise regarding faulting, higher water levels, etc. No comparison has been made to existing conditions in the calibration section and as such it is not known how the model actually replicates reality. A couple of potentially conservative assumptions do not exclude the potentially non-conservative assumptions made elsewhere. Without transient calibration, sensitivity and/or verification assessments it is not possible to say which assumptions out-weight the others in the nature of how conservative the model is.

The assessment provides two options for reclamation of the mine void. The results for Option 2 indicate that additional recharge would occur to the bedrock aquifers and by inference the alluvium as a result of higher recharge to the spoil and a higher recovered water level. The Report also states that there are no risks to water quality as a result of this increased recharge. How is this conclusion consistent with the numerous salinity studies and reclamation projects throughout NSW, and Australia in general, that has found that clearing of forests in the higher topography area led to rising water levels and salinity problems in the lower lying areas as a direct result of increase recharge from rainfall?

Along these same lines – it is not clear how the modelling has accounted for increased recharge from any changes to land use outside the pit area.

3.1.8 Sensitivity Analyses

Sensitivity analyses have been provided for predictive models. These simulations provide a reasonable bound for the impact assessment. Noel Merrick’s independent review provides some recommendations for improvement.

3.1.9 Uncertainty Analyses

No formal uncertainty analyses (i.e. Monte Carlo simulations, etc.) have been presented. This is not uncommon within the practice as computational, budgetary and time constraints often limit the ability to perform these analyses.

3.2 Director General Requirements

The DGRs list the following requirements that pertain to the groundwater assessments:

- a risk assessment of the potential environmental impacts of the project, identifying key issues for further assessment;
- a detailed assessment of the key issues specified below, and any other significant issues identified in the risk assessment (see above), which includes:
    - A description of the existing environment, using sufficient baseline data;
    - An assessment of potential impacts of the project, including any cumulative impacts, taking into consideration any relevant guidelines, policies, plans and statutory provisions (see below); and
    - A description of the measures that would be implemented to avoid, minimise and if necessary, offset the potential impacts of the project, including detailed contingency plans for managing any significant risk to the environment.
- a statement of commitments, outlining all the proposed environmental management and monitoring measures
- Soil and Water
    - detailed modelling of the potential surface water and groundwater impacts of the project;
    - a detailed site water balance, including a description of the measures to be implemented to minimise water use on site;
    - a detailed assessment of the potential impacts of the project on:
        - the quality and quantity of both surface water and ground water resources;
        - water users, both in the vicinity of and downstream of the project;
        - the riparian and ecological values of the watercourses both on site and downstream of the project; and
        - environmental flows; and
    - a detailed description of the proposed water management system for the project and water monitoring program.

The first main bullets are the context by which the final two main bullets will be discussed.

Figures are provided that depict the zone of impact or cone of depression estimated with the proposed mine plane. The zone of impacts is directly influenced/constrained by the alluvial system in all predictive simulations, including the cumulative impact simulations. Therefore this interaction is of direct importance to the impact assessment. As previously stated, it has not been demonstrated that the model replicates reality in depicting this relationship or that it is even conservative.

The impact assessment does not account for arguably the greatest cumulative impact which is the current declining water levels in the alluvial systems.

Pumps are rarely set any deeper than required due to extra electrical and capital costs. Given falling water level conditions within the alluvial aquifer, freeboard above many pumps are likely to already be minimal if non-existent. Mitigation measures for negotiating with land holders to lower pumps, replace bores, etc. to compensate for yield losses attributable to mining related impacts has been recommended but it is unclear how the cause of yield losses will be determined given the background conditions.

Water quality impacts from site activities are adequately covered with recommendations for mitigation and monitoring. One notable exclusion, though, is addressing any potential risk of salinity related impacts from increased recharge at topographically higher areas.

The majority of the impact assessment section is dedicated to changes in flow rates in the alluvium, to mine void, or the interaction between bedrock and alluvium. However, the modelling report has provided no evidence, qualitatively or quantitatively, that the model replicates reasonable estimates of current flow rates. As such, confidence in the impact assessment is limited.

Water management measures, including measures to reduce water use, are not provided. However the monitoring recommendations and data management and reporting recommendations are sound and should be included in the consent requirements, if approved. Particular weight should be given to the Mine Water Seepage Monitoring requirements for the following reasons:

- the model is not calibrated to flows and as such the estimate provided of losses to the alluvium is largely uncertain. Good monitoring and water balance on seepage inflows to the mine will indicate how close the current estimate is.

- any future revisits to the model should include a transient calibration, of which pit inflows will be required to constrain the model solution. It is not in MCCC and Namoi Waters interest for them to do the same thing as Boggabri Coal and say they cannot do better modelling simply because they are not collecting the necessary information. AGE has done well to provide recommendations such that future work can provide greater confidence in the hydrogeologic assessments.

- The project will require licensing of water take and/or water trading to offset inflows. Therefore as accurate an estimate as possible is in all parties' interests.

A description of the water level and quality monitoring systems has been provided and is relatively standard for this type of project. It is noted that a recommendation is provided for reviews of the monitoring data and model accuracy every 5 years. There is concern here with the idea of improving your understanding of impacts after the project is already started and underway. Adopting this approach undermines the EA process by allowing a project to go forward without having confidence in what impacts will occur - essentially rendering the process a function of creating compensation rather than assessing whether the project should be approved.

4. Conclusions and Recommendations

The modelling work conducted thus far is considered to be consistent with the fundamental guiding principle of best practice as defined by Hugh Middlemis (2004) in *Benchmarking Best Practice for Groundwater Flow Modelling*:

> *The fundamental guiding principle for best practice modelling is that model development is an ongoing process of refinement from an initially simple representation of the aquifer system to one with an appropriate degree of complexity. Thus, the model realisation at any stage is neither the best nor the last, but simply the latest representation of our developing understanding of the aquifer system.*

Based upon the current understanding of the work conducted presented in the AGE 2011 report, the following conclusions and recommendations are presented:

- Overall the work presented is in line with industry best practice, with the caveat above that modelling is an ongoing process of increased complexity often balanced by the practical limitations of budget and time.

- The report and presentation of the work conducted is of a high quality and is easily understood with good use of diagrams.

- A thorough background literature search has been completed and is well documented and used as a base for the conceptual and numeric model.

- Using the MDBC guidelines checklist, the modelling is found to be deficient and/or lacking in the areas of calibration, verification, sensitivity analyses and uncertainty analyses – each to varying degrees. The end result is a deficient demonstration or basis by which to have any real confidence that what is being provided is the best estimate or even worst case, in particular with flow rates which form the majority of the impact discussion. Water level hydrograph comparing the predicted and measured water levels for the first 5 years of the predictive simulation could go a long way to providing confidence the model actually replicates reality.

- The primary risks of impact being assessed are associated with the alluvial systems yet the connection between the alluvial and bedrock systems are not well explored either through field testing, literature research, vertical water level gradients, and or model sensitivity assessments. Further work should be conducted, including field studies such as pumping tests and model sensitivity assessments to quantify this interaction.

- The cumulative impact assessment should consider the declining water levels within the alluvial systems along with the impacts of the surrounding mines as currently presented.

- A clear method for identifying mining related loss of well yield from background yield losses should be defined up front to eliminate any confusion or difficulties after the fact.

In summary, the overall impression left after the review is that the work done is competent and well presented, however it is the work not done that leaves cause for concern and uncertainty.

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5. References

Australasian Groundwater and Environmental Consultants, Pty, Ltd. (October 2010) *Continuation of Boggabri Coal Mine Groundwater Assessment*. Prepared for Boggabri Coal Pty Limited, http://majorprojects.planning.nsw.gov.au.

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NSW Department of Planning (2011), *Maules Creek Coal Project (MP 10_0138) Director General Requirements,* http://majorprojects.planning.nsw.gov.au

Appendix A

Glossary

Aquiclude	Low-***permeability*** unit that forms either the upper or lower boundary of a groundwater flow system.
Aquifer	Rock or sediment in a formation, group of formations or part of a formation that is saturated and sufficiently permeable to transmit economic quantities of water to bores, wells and springs.
Aquifer properties	Characteristics of an aquifer that determine its hydraulic behaviour and its response to abstraction.
Aquifer, confined	Aquifer that is overlain by a confining, low permeability strata. The ***hydraulic conductivity*** of the confining bed is significantly lower than that of the aquifer.
Aquifer, semi-confined	Aquifer confined by a low-***permeability*** layer that permits water to slowly flow through it. During pumping, recharge to the aquifer can occur across the confining layer; also known as a leaky artesian or leaky confined aquifer.
Aquifer, unconfined	Also known as a water table or phreatic aquifer. An aquifer in which there are no confining beds between the zone of saturation and the surface. The water table is the upper boundary of unconfined aquifers.
Aquitard	Low-permeability unit that can store groundwater and also transmit it slowly from one aquifer to another. Aquitards retard but do not prevent the movement of water to or from an adjacent aquifer.
Artesian water	Groundwater that is under pressure when tapped by a ***bore*** and is able to rise above the level at which it is first found. It may or may not flow out at ground level. The pressure in such an aquifer commonly is called artesian pressure, and the formation containing artesian water is an artesian aquifer or confined aquifer.
Australian Height Datum (AHD)	Reference point (very close to mean sea level) for all elevation measurements, and used for correlating depths of aquifers and water levels in bores.
Baseflow	Part of stream discharge that originates from groundwater seeping into the stream.
Bore	Structure drilled below the surface to obtain water from an aquifer system.
Boundary	Lateral discontinuity or change in the aquifer resulting in a significant change in ***hydraulic conductivity***, ***storativity*** or recharge.

Cone of depression	Depression of the ***potentiometric*** surface, which has the shape of an inverted cone, and develops around a production ***bore*** from which water is being drawn. It defines the area of influence of a bore.
Confining layer	Body of relatively impermeable material that is ***stratigraphically*** adjacent to one or more aquifers; it may lie above or below the aquifer.
Discharge	Volume of water flowing in a stream or through an ***aquifer*** past a specific point in a given period of time.
Discharge area	Area in which there are upward or sideways components of flow in an aquifer.
Drawdown	Lowering of the water table in an unconfined aquifer or the ***potentiometric*** surface of a confined aquifer.
Fissility	The property of rocks to split down planes of weakness.
Fracture	Breakage in a rock or mineral along a direction or directions that are not cleavage or ***fissility***.
Fractured rock aquifer	Occurs in sedimentary, igneous and metamorphosed rocks that have been disturbed, deformed, or weathered, and which allow water to move through joints, bedding plains and faults. Although fractured rock aquifers are found over a wide area, they generally contain much less groundwater than alluvial and porous sedimentary aquifers.
Groundwater	Water contained in interconnected pores located below the water table in an unconfined aquifer or located in a confined aquifer.
Groundwater flow	Movement of water through openings in sediment and rock; occurs in the zone of saturation.
Groundwater flow system	Regional aquifer or aquifers within the same geological unit that are likely to have similar recharge, flow, yield and water quality attributes.
Hydraulic conductivity	The rate with which water can move through pore spaces or fractures. It depends on the intrinsic ***permeability*** of the material and on the degree of saturation.
Hydraulic gradient	Change in total head (see below) with a change in distance in a given direction, which yields a maximum rate of decrease in head.

Hydraulic head	Specific measurement of water pressure or total energy per unit weight above a datum. It is usually measured as a water surface elevation, expressed in units of length. The hydraulic head can be used to determine a hydraulic gradient between two or more points.
Hydrogeology	Study of the interrelationships of geologic materials and processes with water, especially groundwater.
Hydrology	Study of the occurrence, distribution, and chemistry of all waters on the Earth.
Hydrostatic pressure	The pressure exerted by a fluid at equilibrium due to the force of gravity.
Infiltration	Flow of water downward from the land surface into and through the upper soil layers.
Parameterisation	The process of defining the parameters necessary for the specification of a model.
Perched water	Unconfined groundwater separated from an underlying body of groundwater by an unsaturated zone and supported by an ***aquitard*** or ***aquiclude***.
Permeability	Property or capacity of a porous rock, sediment, clay or soil to transmit a fluid. Measures the relative ease of fluid flow under unequal pressure. ***Hydraulic conductivity*** is a material's ***permeability*** to water at the prevailing temperature.
Permeable material	Material that permits water to move through it at perceptible rates under the hydraulic gradients normally present.
Piezometer (monitoring well)	Non-pumping monitoring well, generally of small diameter, which is used to measure the elevation of the water table and/or water quality. A piezometer generally has a short well screen through which water can enter.
Porosity	Proportion of interconnected open space within an aquifer, comprised of intergranular space, pores vesicles and fractures.
Porosity, primary	Porosity that represents the original pore openings when a rock or sediment formed.
Porosity, secondary	Porosity caused by fractures or weathering in a rock or sediment after it has been formed.

Potentiometric surface	Surface to which water in an aquifer would rise by ***hydrostatic pressure***.
Pumping test	Test made by pumping a bore for a period of time and observing the change in hydraulic head in the aquifer. It may be used to determine the capacity of the bore and the hydraulic characteristics of the aquifer.
Recharge	Process that replenishes groundwater, usually by rainfall infiltrating from the ground surface to the water table and by river water entering the water table or exposed aquifers; addition of water to an aquifer.
Recharge area	Area in which there are downward components of hydraulic head in the aquifer. Infiltration moves downward into the deeper parts of an aquifer in a recharge area.
Recovery	Difference between the observed water level during the recovery period after pumping stops and the water level measured immediately before pumping stopped.
Residence time	Time that a water source spends in storage before moving to a different part of the hydrological cycle (ie it could be argued it is a rate of replenishment).
Saturated zone	Zone in which the voids in the rock or soil are filled with water at a greater pressure than atmospheric. The water table is the top of the saturated zone in an unconfined aquifer.
Sedimentary aquifers	Occur in consolidated sediments, such as porous sandstones and conglomerates, in which water is stored in the intergranular pores, and limestone, in which water is stored in solution cavities and joints. They are generally located in sedimentary basins that are continuous over large areas, they may be tens or hundreds of metres thick, and they contain the largest groundwater resources.
Specific yield	Ratio of the volume of water a rock or soil will yield by gravity drainage to the volume of the rock or soil. Gravity drainage may take many months to occur.
Spring	Location where groundwater emerges on to the ground surface. Water may be free flowing or slowly seeping.
Storativity	Volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. It is equal to the product of specific storage and aquifer thickness. In an unconfined aquifer, the storativity is equivalent to specific yield.

Stratigraphy	The study of stratified rocks (sediments and volcanics), including their sequence in time, the character of the rocks and the correlation of beds in different localities.
Surface water-groundwater interaction	Occurs in two ways: (1) Streams gain water from groundwater through the streambed when the elevation of the water table next to the streambed is greater than the water level in the stream. (2) Streams lose water to groundwater by outflow through streambeds when the elevation of the water table is lower than the water level in the stream.
Transmissivity	Rate at which water of a prevailing density and viscosity is transmitted through a unit width of an aquifer or confining bed under a unit hydraulic gradient. It is a function of properties of the liquid, the porous media, and the thickness of the porous media.
Unconfined aquifer	Where the groundwater surface (water table) is at atmospheric pressure and the aquifer is recharged by direct rainfall infiltration from the ground surface.
Unsaturated zone	That part of an aquifer between the land surface and water table. It includes the root zone, intermediate zone and capillary fringe.
Water table	Surface in an unconfined aquifer or confining bed at which the pore water pressure is atmospheric. It can be measured by installing shallow wells extending a few feet into the zone of saturation and then measuring the water level in those wells.
Well	Any structure bored, drilled driven or dug into the ground, (which is deeper than it is wide), to reach groundwater.

Appendix B

MDBC Review Checklist

MODEL REVIEW: Maules Creek Coal Project – Groundwater Impact Assessment

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?		Missing	Deficient	Adequate	Very Good			
1.2	Is the level of model complexity clear or acknowledged?		Missing	No	Yes				
1.32	Is a water or mass balance reported?		Missing	Deficient	Adequate	Very Good			
1.4	Has the modelling study satisfied project objectives?		Missing	Deficient	Adequate	Very Good			
1.5	Are the model results of any practical use?			No	Maybe	Yes			
2.0	**DATA ANALYSIS**								
2.1	Has hydrogeology data been collected and analysed?		Missing	Deficient	Adequate	Very Good			This area has had many previous studies and the project proponent has provided additional investigations to supplement a historic database.
2.2	Are groundwater contours or flow directions presented?		Missing	Deficient	Adequate	Very Good			
2.3	Have all potential recharge data been collected and analysed? (rainfall, streamflow, irrigation, floods, etc.)		Missing	Deficient	Adequate	Very Good			
2.4	Have all potential discharge data been collected and analysed? (abstraction, evapotranspiration, drainage, springflow, etc.)		Missing	Deficient	Adequate	Very Good			Private land owner abstraction not obtained or used. It is known that NOW provided water use records to the Namoi Water Study of which Aston Resources is a member and as such should have access to the data.
2.5	Have the recharge and discharge datasets been analysed for their groundwater response?		Missing	Deficient	Adequate	Very Good			
2.6	Are groundwater hydrographs used for calibration?			No	Maybe	Yes			
2.7	Have consistent data units and standard geometrical datums been used?			No	Yes				Some inconsistencies as noted in Noel Merrick's review.

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
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			
3.3	Is there a graphical representation of the modeller's conceptualisation?		Missing	Deficient	Adequate	Very Good			
3.4	Is the conceptual model unnecessarily simple or unnecessarily complex?			Yes	No				
4.0	**MODEL DESIGN**								
4.1	Is the spatial extent of the model appropriate?			No	Maybe	Yes			
4.2	Are the applied boundary conditions plausible and unrestrictive?		Missing	Deficient	Adequate	Very Good			The explicit boundary conditions input to the model seem to be unrestrictive. However the fixed parameterisation of the alluvium makes this in effect a prescribed boundary condition and the modelling results presented indicate that the alluvium is restricting any drawdown propagation. This relatively important role the alluvium is playing is not balanced by presentation of field testing, data analysis, or sensitivity and/or uncertainty analyses.
4.3	Is the software appropriate for the objectives of the study?			No	Maybe	Yes			
5.0	**CALIBRATION**								

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
5.1	Is there sufficient evidence provided for model calibration?		Missing	Deficient	Adequate	Very Good			The level of statistical calibration and presentation is adequate for the steady state model. It is also noted that the predictive simulation starts in 2006 when mining began – yet no comparisons are provided either as calibration or verification that the predicted water levels match those measured of the same time period (either in absolute head values or rate of decline). No transient calibration is conducted despite the fact this study has more information available to it than most others which still manage to provide a transient calibration exercise to demonstrate a model's ability to at least reasonably represent response to flux changes in the system.
5.2	Is the model sufficiently calibrated against spatial observations?		Missing	Deficient	Adequate	Very Good			A large residual error is still noted, especially in the bedrock units.
5.3	Is the model sufficiently calibrated against temporal observations?		Missing	Deficient	Adequate	Very Good			
5.4	Are calibrated parameter distributions and ranges plausible?			No	Maybe	Yes			
5.5	Does the calibration statistic satisfy agreed performance criteria?	Unknown	Missing	Deficient	Adequate	Very Good			None stated

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
5.6	Are there good reasons for not meeting agreed performance criteria?	Not Applicable	Missing	Deficient	Adequate	Very Good			No agreed performance criteria were documented. Reasons presented in the report for not performing a transient calibration (at least for the bedrock aquifers alone) are not plausible and/or fully justified.
6.0	**VERIFICATION**								
6.1	Is there sufficient evidence provided for model verification?		Missing	Deficient	Adequate	Very Good			None provided even though datasets are said to exist and the predictive simulation included the previous 5 years of mining.
6.2	Does the reserved dataset include stresses consistent with the prediction scenarios?	Not Applicable	Unknown	No	Maybe	Yes			
6.3	Are there good reasons for an unsatisfactory verification?	Not Applicable	Missing	Deficient	Adequate	Very Good			
7.0	**PREDICTION**								
7.1	Have multiple scenarios been run for climate variability?		Missing	Deficient	Adequate	Very Good			
7.2	Have multiple scenarios been run for operational/management alternatives?	Unknown	Missing	Deficient	Adequate	Very Good			Two mine closure options are presented.
7.3	Is the time horizon for prediction comparable with the length of the calibration / verification period?		Missing	No	Maybe	Yes			Calibration is steady state (i.e. no time period) and no verification is provided.
7.4	Are the model predictions plausible?			No	Maybe	Yes			
8.0	**SENSITIVITY ANALYSIS**								

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
8.1	Is the sensitivity analysis sufficiently intensive for key parameters?		Missing	Deficient	Adequate	Very Good			Sensitivity analysis for calibration is not presented. Minimal sensitivity analyses are performed for predictive simulations. Note Noel Merrick's comments/suggestions for better ranges in storage values for sensitivity assessments.
8.2	Are sensitivity results used to qualify the reliability of model calibration?		Missing	Deficient	Adequate	Very Good			No sensitivity for model calibration is provided
8.3	Are sensitivity results used to qualify the accuracy of model prediction?		Missing	Deficient	Adequate	Very Good			Good presentation of bounds of estimate. Noted Noel's Merrick's suggestions for improvement (8.1).
9.0	**UNCERTAINTY ANALYSIS**								
9.1	If required by the project brief, is uncertainty quantified in any way?	Unknown	Missing	No	Maybe	Yes			Unknown if required by project brief but quantification of uncertainty is not provided – other than that implied by the predictive sensitivity simulations. However a section is provided that provides some qualitative description of overall uncertainty.
	TOTAL SCORE								**PERFORMANCE: %**